Bulletin 103 Mineral Technology 11

DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, SECRETARY

BUREAU OF MINES
VAN. H. MANNING, DIRECTOR

MINING AND CONCENTRATION OF CARNOTITE ORES

BY
KARL L. KITHIL AND JOHN A. DAVIS

[Prepared under a cooperative agreement with the National Radium Institute]

WASHINGTON
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PREFACE.

In 1912 the Bureau of Mines had its attention called to the value of the carnotite ore of Colorado and Utah as a source of radium and to the need of investigations being made to prevent waste of low-grade carnotite, to enable the miner to receive a better price for his product, and to insure the profitable recovery of the highest possible proportion of the radium in the ore. The need of comprehensive research was increased by the carnotite deposits being situated on public lands and constituting the largest known supplies of radium ore in the world. Fortunately the bureau was able to interest Dr. James Douglas, of New York City, and Dr. Howard A. Kelly, of Baltimore, Md., who wished to procure a supply of radium for use in the treatment of cancer in hospitals with which they were connected. The suggestion was made that they form a radium institute. Accordingly, the National Radium Institute was incorporated for the purpose of studying the best methods of producing uranium, vanadium, and radium, and the mining and concentration of ores from which these products may be obtained for use in radium therapy.

Subsequently, at the suggestion of the institute, a cooperative agreement was made under which the Bureau of Mines undertook to provide the services of skilled chemists and mineral technologists for the supervision of the mining and concentrating of the carnotite, and the National Radium Institute agreed to furnish the necessary funds for mining and concentrating a sufficient supply of ore and for recovering from it the radium, uranium, and vanadium. Under this agreement a radium-recovery plant was built in Denver, Colo. The plant began commercial operation in June, 1914, and when it stopped work in January, 1917, about 8½ grams of radium had been extracted. The cost of recovery under the methods devised by the Bureau of Mines was only about one-third the current price for radium. In addition, methods of saving the uranium and vanadium in the ores and of obtaining the metals in a pure state were perfected.

The agreement between the National Radium Institute and the Bureau of Mines expired in 1916. As a result of the work under this agreement, the Bureau of Mines has been able not only to demonstrate that radium can be produced at a cost much less than the selling price, but it also has been able to show how losses in mining and concentrating carnotite can be prevented and our resources of this wonderful element conserved. Finally, for an expenditure of less

than $38,000, the bureau has received as its share of the results of the cooperative agreement more than $100,000 worth of radium.

The work of the Denver plant was discussed in Bureau of Mines Bulletin 104.[a] In the present bulletin K. L. Kithil, mineral technologist, and J. A. Davis, assistant mining engineer, describe the methods used in mining and concentrating the carnotite treated at Denver. As the workable carnotite deposits of Colorado and Utah, though lying near the surface, are relatively small, vary greatly in richness, and are extremely irregular in distribution, methods such as are ordinarily used for prospecting and mining shallow deposits have to be modified. Also, it is necessary to examine the ore carefully, sort it closely, and frequently test its radium content with the electroscope. Finally, the carnotite deposits are mostly in an arid region, where water for any purpose is scarce, so that dry rather than wet methods of concentration must be used at most places. Hence the authors have given detailed information in regard to many operations that might receive little notice in an account of the mining of most metals, but the presentation of these facts in regard to carnotite is necessary because of their bearing on profitable mining and concentration, the utilization of low-grade ore, and the prevention of waste.

VAN. H. MANNING,
Director.

[a] Parsons, C. L., Moore, R. B., Lind, S. C., and Schaefer, O. C., Extraction and recovery of radium, uranium, and vanadium from carnotite. 1915. 124 pp.

MINING AND CONCENTRATION OF CARNOTITE ORES.

By Karl L. Kithil and John A. Davis.

Chapter I. THE MINING OF CARNOTITE ORES BY THE NATIONAL RADIUM INSTITUTE.

DISTRIBUTION AND CHARACTER OF CARNOTITE DEPOSITS.

The principal deposits of carnotite, so far as now known, are confined to a well-defined area lying in the southwestern part of Colorado and the southeastern part of Utah (see Pl. I). Approximately, this area is bounded as follows: On the east by a line extending from a few miles east of the southwest corner of the State of Colorado, to a point about 6 miles west of Naturita, thence directly north to the San Miguel River, thence along the course of this river and the Dolores River to Mesa Creek, thence toward the headwaters of Mesa, Blue, and Calamity Creeks on the south side of the Uncompahgre Mountains; on the north by a line extending from the last-named point westerly to the San Rafael Swell near Green River, Utah; on the west by a line extending from San Rafael Swell to the Henry Mountains, and on the south by a line extending from the Henry Mountains toward the southeast corner of the State of Utah.

This area includes the main districts wherein carnotite has been found, claims have been located, and the ore produced. There are of course, extensive tracts within this area which do not contain carnotite in paying quantities. In places the carnotite beds have been entirely eroded or are not present, or lie so deep that mining is not practicable. The main deposits of carnotite within the area lie in different districts which in Colorado are as follows: Summit and Bush Canyons in Dolores and San Miguel Counties; McIntyre, Gypsum Valley, and Bull Canyon districts; the Paradox Valley, La Sal Creek, Roc Creek, Long Park, Hieroglyphic, Saucer Basin, and Hydraulic districts in Montrose County; Mesa, Blue, and Calamity Canyon districts and the Gateway area in Mesa County. The included districts in Utah are as follows: The Green River and San Rafael Swell district in Garfield County; the Thompson deposits in Grand County;

the Dry Valley, Yellow Wash, and Lisbon Valley districts in San Juan County; the district around the Henry Mountains in Garfield County; and the deposits recently reported in Montezuma Canyon (south of Monticello) in San Juan County.

Outside of the area described there are scattered deposits north of the Denver & Rio Grande Railroad at Coal Creek, near Meeker, Rio Blanco County; along Skull Creek and Red Wash, near Rangely, Routt County; on Horse Mountain, near Eagle, Eagle County, and in South Park, near Garos, in Park County, Colo.

The claims leased from the Crucible Steel Mining & Milling Co. by the National Radium Institute are situated on the north side of East Paradox Valley, in the Long Park and Hydraulic districts. The National Radium Institute has mined no ore except from its leased claims in the Long Park district.

For information regarding the general geology of the region, the probable origin of the ores, and descriptions of other carnotite deposits, the reader is referred to the literature [a] on these subjects.

The carnotite of the area described is deposited in a light-colored, cross-bedded sandstone that lies almost horizontal between the La Plata formation below and the Dakota sandstone (conglomerate) above, and is included in the McElmo formation, which is of Jurassic age. Underlying the white sandstone of the La Plata is the Dolores formation, or "Red Beds," which is plainly visible along and just below the rim rocks of the steep canyon walls in many of the carnotite districts. Along such canyons the ore crops out at different places, so that prospecting is comparatively easy. For ore on the benches and on the mesa prospecting is more difficult, especially where the ore lies at some depth and no surface indications are visible. The carnotite deposits are flat, lenticular, and irregular, varying greatly in extent and thickness. The carnotite itself forms incrustations on exposures of the white sandstone, in joints and fractures of the rock, and is deposited around and between individual sand grains, replacing the original cement. The Utah and Colorado carnotite is amorphous, and to the naked eye appears as a very fine yellow powder. It is often granular, and as a rule can be readily separated from the individual sand grains.

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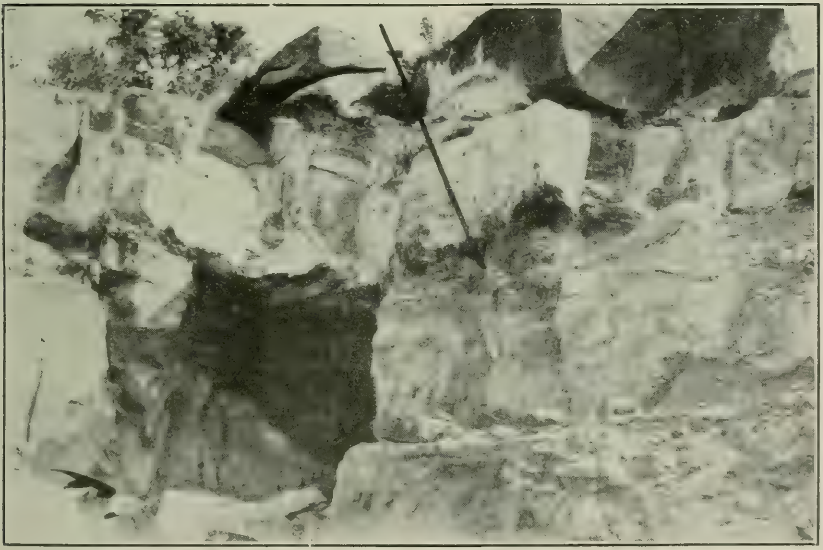
[a] Hillebrand, W. F., and Ransome, F. L., On carnotite and associated vanadiferous minerals in western Colorado: U. S. Geol. Survey Bull. 262, 1905, pp. 9–31. Hillebrand, W. F., and Ransome, F. L., Carnotite and associated minerals in western Colorado: Am. Jour. Sci., ser. 4, vol. 10, 1900, p. 134. Fleck, Herman, and Haldane, W. G., A study of the vanadium and uranium belts of southern Colorado: Report State Bureau of Mines, Colorado, 1905–6, pp. 47–115. Boutwell, J. M., Vanadium and uranium in southeastern Utah: U. S. Geol. Survey Bull. 260, 1905, pp. 200–210. Gale, H. S., Carnotite in Rio Blanco County, Colo.: U. S. Geol. Survey Bull. 315, 1907, pp. 110–117. Gale, H. S., Carnotite and associated minerals in western Routt County: U. S. Geol. Survey Bull. 340, 1908, pp. 257–262. Hess, F. L., Carnotite near Green River, Utah: U. S. Geol. Survey Bull. 530, 1911, pp. 161–164. Moore, R. B., and Kithil, K. L., A preliminary report on uranium, radium, and vanadium: Bull. 70, Bureau of Mines, 1913, 100 pp. Hess, F. L., A hypothesis for the origin of the carnotite of Colorado and Utah: Econ. Geol., vol. 9, 1914, pp. 675–688. Kennan, Chester T., On carnotite deposits and the Rand banket: Min. and Sci. Press, vol. 110, 1915, pp. 620–621.

A. STRATUM OF CARNOTITE AND VANADIC SANDSTONE (SEE CROSSES) OF THOMPSONS DEPOSITS, 16 MILES SOUTHEAST OF THOMPSONS, UTAH.



B. OPENING OF NORTH STAR MINE, LONG PARK, COLO., SHOWING CARNOTITE OUTCROP.

MINING CLAIMS OF THE NATIONAL RADIUM INSTITUTE.

LOCATION OF CLAIMS.

All of the claims mined by the National Radium Institute were leased on a royalty basis from the Crucible Steel Mining & Milling Co., a subsidiary company of the Crucible Steel Co. of America. Of the claims leased, 11 were in or near Long Park, Montrose County, Colo., 6 were in the Hydraulic district, Montrose County, and 10 were in the vicinity of Sawpit, a station on the Rio Grande Southern Railway, a few miles west of Telluride, San Miguel County. The last-named claims contain no carnotite, but vanadium solely. Of the carnotite claims, only those in the Long Park group were mined, all the ore required being obtained there.

Long Park is the name given to a plateau lying north of East Paradox Valley. This plateau is roughly elliptical in shape, being about three and a half miles long and perhaps a mile or a mile and a half across at its widest part. The park slopes gently northeast to the base of an escarpment, which is capped by Dakota sandstone, and pierced by three canyons that carry the drainage from the park to the San Miguel River. Toward the southwest the park rises gradually for about half a mile to the crest of the rim of East Paradox Valley.

The camp of the National Radium Institute is in a small box canyon at the extreme western end of the park. It is 58 miles from Placerville, the nearest railroad station, and 15¾ miles from Naturita, the nearest town and post office on the road to Placerville. The camp buildings and the spring are on the Maggie C mill site, a rectangular piece of ground comprising about 5 acres; it and the Maggie C lode are the only patented claims in the vicinity. A view of the camp is shown in Plate VI, *A* (p. 48).

The Vanadite and Uranite claims are nearest the camp. The Vanadite adjoins the mill site, as shown on the map (fig. 1), and embraces the crest and rim of a ridge, or hogback, about 150 feet high, capped by the sandstone that usually carries the carnotite. This ridge forms the north wall of the canyon in which the camp lies. The Uranite claim crosses the end of the Vanadite claim, and extends down the northern slope of the hogback. Overlapping the end of the Uranite and roughly parallel to the Vanadite claim is the Henry Clay, which lies wholly on the north slope of the ridge.

Of all the claims in Long Park the Maggie C is the most important, as it has been by far the best producer. The southern end of this claim is on the level floor of the park, one-quarter of a mile east of the mill site (see fig. 1). About 300 feet from its southern end the claim crosses a continuation, about 25 or 30 feet high, of the ridge on which the Vanadite, Uranite, and Henry Clay claims are located. From

the crest of the ridge the ground slopes gradually for about 500 feet to a gully, dry except in storms, running nearly at right angles with the axis of the claim; on the other side of the gully the ground rises over another low ridge and then slopes downward to the northern end of the claim.

The Florence, Nellie, and Great Western claims (see fig. 1) are not in the park itself, but on the side of a hill in the drainage area of Hieroglyphic Canyon. The Medea claim lies on a low spur projecting into the southern edge of the park about 2½ miles from the camp. The Dixie claim is in the rim rocks of East Paradox Valley just east of the extreme eastern end of the park; and the Buckeye and Noontime claims are in the rim rocks, about 5 miles from the camp, along the road to Naturita.

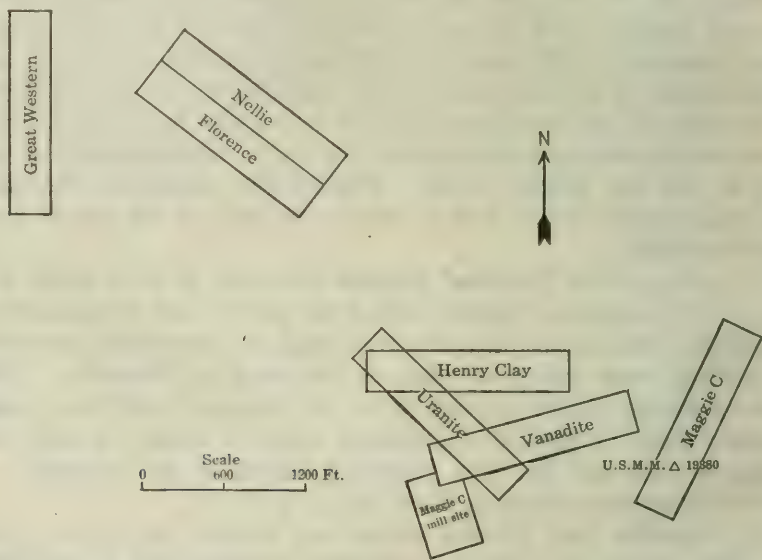
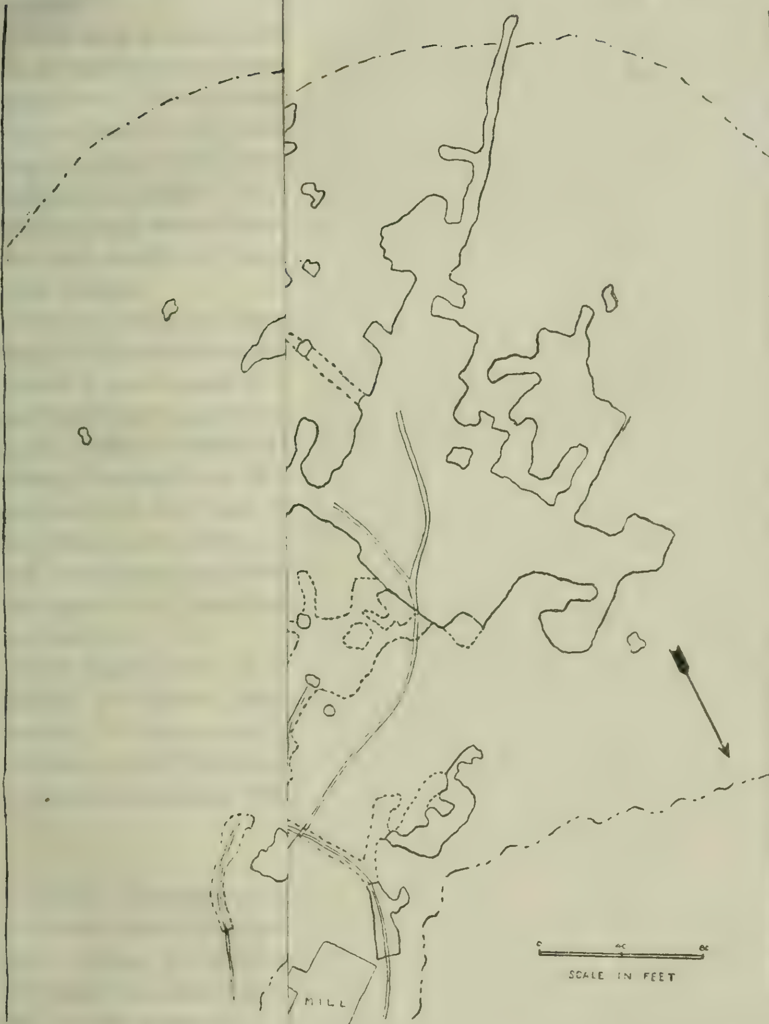


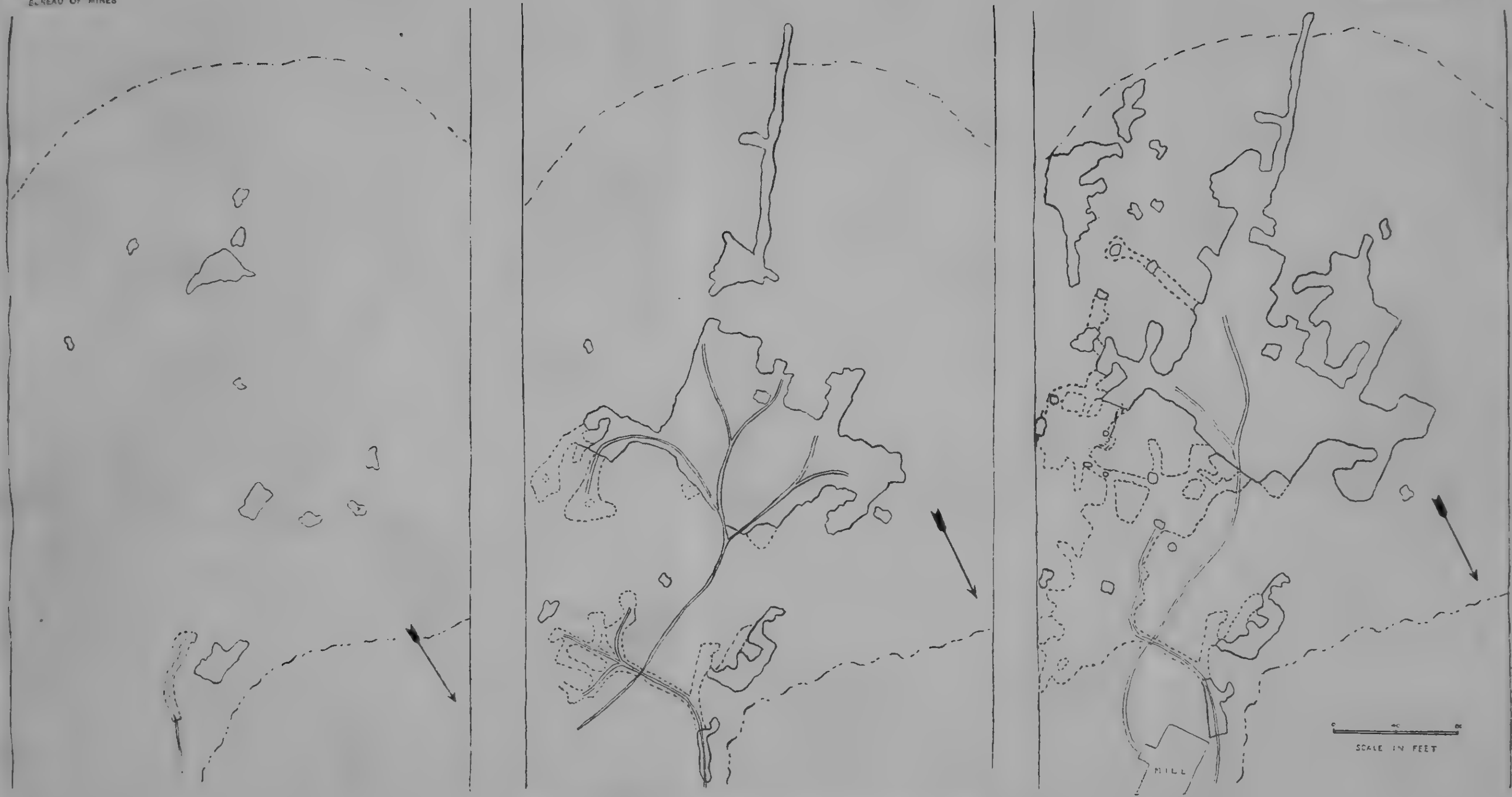
FIGURE 1.—Sketch map o fsome of the claims worked by the National Radium Institute.

DESCRIPTION OF THE CLAIMS.

MAGGIE C.

The ore on the Maggie C claim was found entirely within the area between the low ridge and the gulley described above, and at a fairly definite geologic horizon embracing 10 to 15 feet of sandstone. The main body of the ore comprised an irregular but rather elliptical pocket measuring about 350 feet long by 200 feet wide at the widest part, with its main axis trending northeast. Within this pocket there were three places near which the ore was more abundant and of better grade than elsewhere. The largest of these rich spots occupied most of the southern half of the pocket, and is indicated by the large open


MILL
SCALE IN FEET



SKETCH MAPS SHOWING PROGRESS OF MINING ON MAGGIE C CLAIM.

cut near the center of map 2 in Plate II. This cut included most of the productive part of this pocket, although, as shown on map 3 (Pl. II), the southern limits of the cut were later somewhat extended. The second rich spot, although rather small, was remarkable for the thickness of the ore, for in places solid shipping ore 3 and 4 feet thick extended across the entire face of the development tunnels.

This area is best shown on map 3 (Pl. II), where it is indicated by the dotted lines (representing the underground work), east of the main open cut. The narrow open cut connecting this pocket with the first contained only milling ore, and very little of that. The third large pocket, which was mined by tunneling from the gulley, is also outlined in map 3 (Pl. II). Besides the three large pockets, three smaller ones were found on the Maggie C (see Pl. II), two along the rim rock south of the main lens and one near the entrance to the main tunnel.

Plate II clearly shows the progress of development and mining. Map 1 indicates the amount of work that had been done on this claim before it was leased to the National Radium Institute. In the prospect pits shown, ore was found within a few feet of the surface, except at ×. Map 2 shows the development in February, 1915. Map 3 shows the condition of work on October 15, when the mining of shipping ore for the year 1915 ceased. All of the pillars of the tunnel had then been drawn, including those that carried milling ore only, and the pocket had been connected with the two other large pockets. The position of the shafts or raises for light and air is indicated on the maps.

The production of ore from these various pockets was approximately as follows: Main open cut, 265 tons; large stope, 150 tons; tunnel, 210 tons; small pockets on rim, 8 tons; small pocket on gulley, 10 tons; other underground work indicated on map 3, 7 tons.

Plate III shows a vein in the open-cut workings on the Maggie C.

FLORENCE.

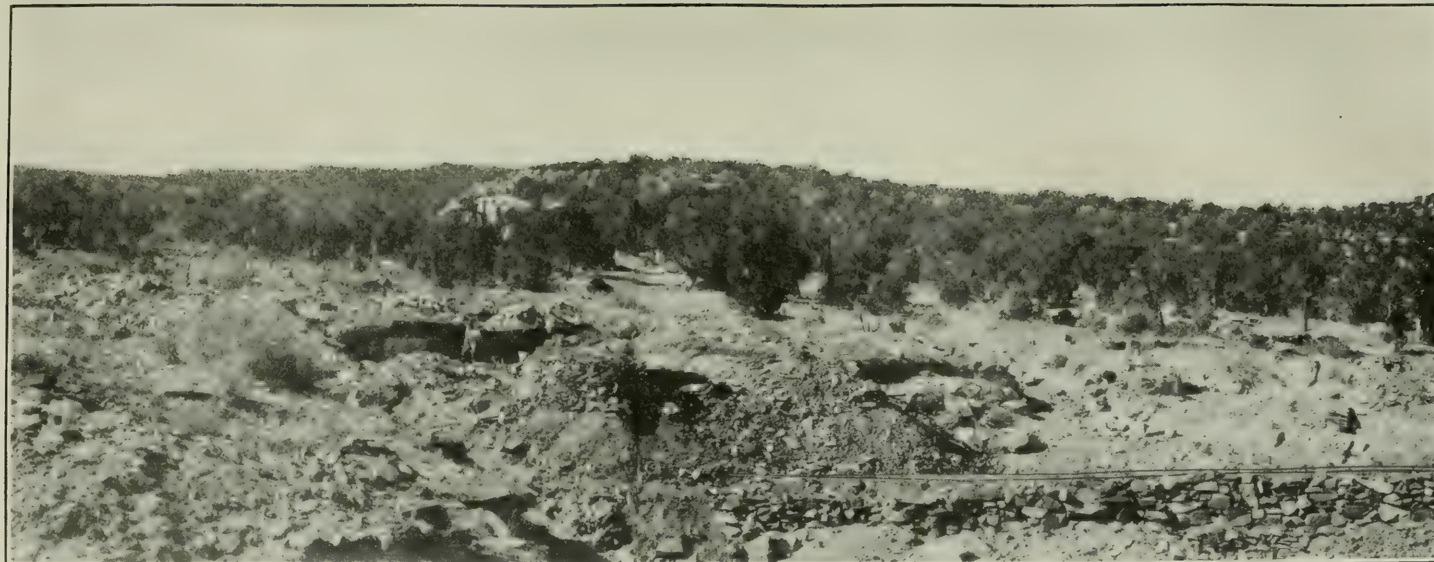
On the Florence claim the main ore body found was in the side of a small gulley that crosses the claim about 300 feet from its eastern end. Along the sides of this gulley, which is dry except in storms, the carnotite-bearing sandstone outcrops; but the ore is pockety and varies greatly in character. On the east side of the gulley, near the north line of the claim, a "bughole" 3 to 5 inches in diameter contained some high-grade carnotite. This ore was so moist and soft when first opened that a miner's spoon could be pushed to its full length into the hole without difficulty. On exposure to the air and drying this high-grade ore became somewhat harder, but could still be crumbled readily with the fingers. Much of the

rock surrounding this "bughole" was so impregnated with carnotite for 18 inches or 2 feet as to make it shipping ore; beyond this the sandstone usually showed traces of uranium and vanadium, but was too low grade to be milling ore. A tunnel driven along this hole for 60 to 75 feet, obtained just about enough ore to pay expenses, but found no considerable pocket. Farther up the gulch and on the same side, ore of entirely different appearance was found as thin bands or laminations in a clearly bedded sandstone. The bands of carnotite were one thirty-second of an inch to 5 or 6 inches across, the extremely thin bands being nearly pure carnotite and the thicker ones being sandstone so impregnated with the carnotite as to carry $2\frac{1}{2}$ to $3\frac{1}{2}$ per cent U_3O_8. The sandstone between the bands of carnotite was in many places highly impregnated with vanadium, the whole forming a mineralized band or vein 2 or 3 inches to 2 feet thick. On the west side of the gulley, about halfway between the center line and the north line of the claim there was a "bughole" similar to that on the east side but not as large; it was followed by a tunnel for about 25 feet, when the ore gradually became laminated and banded, and widened so that the stope measured approximately 20 by 30 feet. At the far end of this stope the ore sloped upward sharply and was exposed in the creek bed. On the mesa west of the gulley smaller pockets, similar to those on the Nellie claim, were found which yielded a few sacks to 3 or 4 tons each, but a large proportion of the ore from the Florence was mined underground, especially in the tunnel and stope.

The Florence claim ranked next to the Maggie C in productiveness, yielding about 140 tons. Work on the claim was continuous for 16 months. Much of the ore was excellent and the total output averaged, by electroscopic tests, 2.90 per cent U_3O_8

NELLIE.

On the Nellie claim, which ranked fourth in productiveness, there were two main pockets, each of which produced over 10 tons of shipping ore. Both pockets were near the surface of the mesa, the average thickness of the overburden removed being only about 3 feet. The first pocket was at nearly the middle of the claim, and the other near the middle of the east half. The ore from these pockets was rather above the average, rarely containing less than 3 per cent U_3O_8. Extensive prospecting revealed several other small pockets which produced a few sacks to a ton or so each, but no other large paying pockets, although the many small outcrops may indicate that more extensive development might prove profitable. Work was carried on continuously during 16 months and the total output was about 42 tons, which averaged higher in uranium than that from any of the other claims worked, the electroscopic tests showing 3.65 per cent U_3O_8.



SURFACE WORKINGS ON MAGGIE C CLAIM.

GREAT WESTERN.

On the Great Western claim ore was mined at three main workings, the first lying at about the middle of the north half of the claim, on the north side of the steep-sided gulley mentioned, the second being south of the center of the claim, on the south side of this gulley, and the third near the middle of the south half of the claim but higher up the hillside than the second.

In the first locality, the ore formed irregular impregnations in fairly massive sandstone. Most of the ore was near the outcrop and was mined by open cut; two tunnels, about 50 feet and 30 feet in length, followed more or less well-defined leads. Several other small pockets were found here in the sandstone outcrop along the rim of the gulley; they yielded a few sacks each, and the rock between was entirely barren. The total production from this locality was approximately 30 tons of shipping ore and a small quantity of milling ore.

In the second locality ore was found in one large pocket and in two smaller ones that were opened in prospecting and mined through short tunnels. The main pocket, which yielded about 30 tons of shipping ore, was also discovered by surface prospecting, but a crosscut about 25 feet long was driven from the gulch to facilitate mining. At the third locality the ore was found in a loose breccia, different sized pieces of carnotite-bearing sandstone being indiscriminately mixed with sand, clay, and angular fragments of barren rock. The mining here was usually by small open cuts that followed the more finely broken material around the larger bowlders, many of which weighed more than 10 tons. In the winter, when the ground was frozen and snow-covered, the ore was followed by small tunnels or drifts with only 2 or 3 feet of cover. The ore was usually good, and numerous pieces carried as much as 6 and 8 per cent U_3O_8. In spite of the irregular distribution of the ore, which necessitated constant prospecting, the claim was worked with profit during the 17 months of active mining, and ranked third in yield. The uranium content of the ore averaged better than 3 per cent U_3O_8.

HENRY CLAY.

Although the Henry Clay claim had been prospected rather extensively before it was leased by the National Radium Institute, and promised to be a good producer, the amount of ore finally discovered was disappointing. Two prospect holes showed considerable vanadium ore, but no signs of uranium ore other than a slight yellow stain along joints. The principal pocket of carnotite was in the bottom and along the sides of a small gulley near the center of the claim. This pocket measured about 10 by 25 feet, and the ore was 4 inches to 1 foot thick. During 1915 about 10 tons of shipping ore

and 3 tons of milling ore were taken from this pocket. Mining was chiefly by open cut, although a little carnotite was found near the edge of the main pocket in a tunnel driven about 20 feet on a vanadium-bearing lead in the sandstone. A similar tunnel along a similar promising lead on the opposite side of the gulch was without result. About 2½ tons of shipping ore and 5 tons of milling ore were obtained from a small pocket discovered about 150 feet farther up the gulley in 1915. No more ore was found, although over 37 per cent of the time spent in work on this claim was prospecting. The uranium content of the ore was not high.

MEDEA.

Three pockets of ore were found on the Medea claim. The first had been opened, before the claim was leased, by an open cut about 10 feet long, 5 feet wide, and 8 feet deep, from the end of which a tunnel had been driven for perhaps 25 feet. Several tons of ore were obtained by the National Radium Institute from the sides of the cut and by stoping in the tunnel. This ore averaged fairly high in vanadium, but only a little better than 2 per cent U_3O_8. The second pocket was discovered about 75 feet east, in the same ledge of sandstone. This pocket was found at the surface, but it soon pitched downward, and was followed by a tunnel about 15 feet, when it widened, resulting in a small stope measuring 12 by 15 feet. The ore from this stope was much better than the average from the whole claim, some of it carrying 3.5 per cent U_3O_8. In this stope were found the fissures filled with calcium vanadate and vanadic oxide [a] mentioned on page 44. The third pocket was discovered about 200 feet farther east along the ridge and was also opened by tunneling. It proved to be smaller than either of the others. After this tunnel had been driven about 12 feet the ore ran so near the surface that the roof was taken down; the resulting open cut, about 5 feet wide and 7 feet deep, extended some 15 feet farther. The carnotite here was above the average in vanadium, but rather low in uranium. Its color was decidedly greenish-yellow, and the impregnated sandstone was so evenly bedded as to have almost the appearance of shale.

The Medea was so far from camp and the ore was in general so poor that only one miner was steadily employed, who worked this claim during the whole or a part of 10 of the 17 months. As little prospecting or development was necessary on the Medea, the output of ore, 900 sacks, was excellent for the amount of work done. This was the only claim of the group worked by the National Radium Institute that averaged more than 4 sacks per man per shift, though the cost of production, which included the upkeep of a saddle horse required by the miner, about equals that on the Maggie C.

[a] Hillebrand, W. F., Merwin, H. E., Wright, F. E., Hewettite, metahewettite, and pascoite, hydrous calcium vanadates: Proc. Am. Phil. Soc., vol. 53, 1914, pp. 31–54.

BUCKEYE AND NOONTIME.

During assessment work for 1914 on the Buckeye and Noontime claims, several small pockets of ore were discovered and mined, producing in all about 8 tons of shipping ore, most of it from the Buckeye. A small quantity of milling ore was mined and stored.

Most of the ore found on the Bitter Creek claims was low grade, and because of their distance from the mill and their relative inaccessibility no attempt has been made to treat this ore, although it remains available in case the market price for concentrates should warrant hauling it to a mill. During the assessment work for 1915, only 275 pounds of ore was mined from these two claims. In 1914 the assessment work was done from a small subsidiary camp situated on Bitter Creek, the gulley previously mentioned, along which the claims are located. In 1915, however, the miners doing assessment work were taken to Bitter Creek daily from the main camp.

DIXIE.

Although the Crucible Steel Co. is said to have obtained several sacks of high-grade ore from two "bugholes" on the Dixie claim, the National Radium Institute, after weeks of diligent prospecting, was unable to find any ore at all. The most promising indication was a greenish-yellow vanadium stain on one of the sandstone ledges overlooking East Paradox Valley, but a tunnel more than 25 feet long found no ore there, and in fact no other indication of ore. Under ordinary circumstances this claim would have been promptly dropped, but as the terms of the contract required the National Radium Institute to perform the annual assessment work on all unpatented claims in the Long Park group, the prescribed amount of such work was spent in careful prospecting, as on the Uranite and the Noontime.

VANADITE.

On the Vanadite claim the chief pocket of ore found was in the rimrock of the main ridge above the camp. The pocket extended along the face of the cliff about 30 feet; it was opened by several short tunnels but proved very shallow, the ore invariably giving out at 10 or 12 feet from the face of the cliff. This ore contained more than the average vanadium content, and had a dark greenish-gray color. The uranium and the vanadium mineralization was in more or less well-defined alternate bands. Extensive prospecting revealed only one other pocket on this claim, a small lens at the west end which was taken from a 10-foot tunnel. The total production was about 8 tons of shipping ore and about 10 tons of milling ore, all produced in 1914, and 2 tons of milling ore mined in 1915. The uranium content of all ore from this claim was low.

URANITE.

On the Uranite claim, a subsequent location to both the Henry Clay and Vanadite claims, which it overlaps (See Plate II, page 14), the annual assessment work showed no ore whatever, either of milling or shipping grade, in any part of this claim not included in the other two claims.

PROSPECTING THE CLAIMS.

As the carnotite ore bodies on the Long Park claims were invariably irregular masses or pockets rather than well-defined veins or strata thorough search for such pockets was necessary. Some of the ore bodies contained only a few hundred pounds, but a few occasionally produced as much as 100 tons, although the latter instances were extremely rare. Hence, to insure a steady supply of ore required constant prospecting. Prospecting started when the National Radium Institute began work and continued throughout the period of production. In this way a fairly steady output was maintained in spite of the patchy and irregular distribution of the ore which often gave out suddenly at any one working.

Prospecting methods had to be adapted to the requirements of each claim or situation, and no one indication could be followed with the certainty of finding ore, although there are a number of signs that may indicate its presence. Perhaps the most promising of these was the discovery of float, either a piece of weathered, shaly, rather fine-grained sandstone impregnated with some dark gray-green mineral, or a piece of coarse-grained sandstone containing traces of carnotite and vanadium leached or otherwise weathered. When float was found, the customary methods of prospecting generally led to finding the mother ledge. If the float was of the first mentioned variety, this ledge was usually a black band of mineralized sandstone in which were sometimes seen minute grains of carnotite. In the second instance the grains of carnotite in the ledge were larger and more abundant, often giving the sandstone a yellow tint. In either case, however, the surface indications had to be followed by a test pit, open cut, shaft, or tunnel, according to the topography, and even with all signs favorable the presence of a paying body of ore could not be predicted with any accuracy. On one claim in particular where the signs seemed very promising, weeks of prospecting uncovered no carnotite.

DRILLING.

In prospecting claims where the ore was commonly found close to the surface, a hand churn drill was often a great help. In using this drill, which is a bar of drill steel 12 to 14 feet long and sharpened at

both ends, a vertical hole 4 or 5 feet deep is drilled with an ordinary drill; then the miner inserts the long drill and works it up and down, the drillings being removed with a scraper. With this simple tool it was possible to drive a hole 8, 10, or 12 feet even in hard sandstone. The chief disadvantage lies in the somewhat uncertain indications of the nature of the strata obtained from the sludge. Such a hole can not be kept very clean, so that the exact depth of any ore found is obscured by the particles of ore being mixed with sludge formed in drilling through the rock above. The entrance of the drill into the rock below the ore will be obscured in like manner, so that the exact thickness of the ore body can not be determined. Nevertheless, the churn drill was extremely useful, indicating advantageous places at which to sink shafts and giving approximately the probable depth to ore.

Where the number of workable claims and the amount of prospecting to be done are sufficient to warrant the extra expense, core drills should be used. There are a number of core-drilling machines on the market, some of which have been tried by one company working claims in the carnotite district, with results said to be satisfactory. The advantages of the core drill, which brings up a cylindrical section of the strata being penetrated, over the churn drill are obvious. However, the irregular and pockety nature of the carnotite ore bodies makes even core drilling uncertain unless the holes are closely spaced, for otherwise a number of holes on a claim may miss an important pocket. On the other hand, core drilling should be much less expensive than sinking a shaft, no matter how small, to an equivalent depth. Holes 30 and 40 feet deep were obtained by the company mentioned above and in the absence of surface indications shafts are the only available substitute for drill holes. One objection to using a core drill in Long Park was the amount of water required. The authors are advised that about 60 gallons a day were used with the machine mentioned above, in addition to such water as could be collected and used over again. Where water must be hauled even for drinking and cooking purposes, the use of any considerable amount for drilling becomes a serious consideration.

CHARACTER OF ROCK.

In places the character of the rock was a good indication. The ore was usually found in the more porous parts of the ore-bearing sandstone rather than in the close-grained and highly indurated parts, hence the miners did not expect ore when the rock was "tight," but its beginning to "loosen" was considered a good sign. The ore was often found near and below a sandstone which, upon weathering, had a peculiar structure, resembling a conglomerate with pebbles the size of marbles. This appearance may have been due to differences in the cement, the softer part being eroded by the weather and

leaving the harder parts, although no difference in the nature or texture of the unweathered sandstone was visible. Some ore bodies were discovered solely through the presence of this pseudo-conglomerate. Calcite was often closely associated with the ore, so that in some places its presence led to the discovery of ore. Also carbonaceous material in varying amounts was generally associated with the carnotite, and often served as an indicator.

Places suitable for prospecting were sometimes selected solely on account of the strike and dip of the strata, although the irregular character of the ore bodies frequently made this method uncertain. At some places ore showed plainly at the outcrop; at others a vanadium stain, grayish, greenish, or black, sometimes led to ore when properly followed. The nearest approach to an actual vein was discovered on the Florence claim, where an ore-bearing stratum was practically continuous for 150 to 200 feet. On the Maggie C the ore-bearing zone, though relatively large, was not continuous or along well-defined planes, as prospecting on the farther side of the Maggie C gulley failed to show any evidence of ore. The ore dips in that direction, however, and may lie too deep there to be reached except by drilling.

GENERAL PROCEDURE IN DELIMITING ORE BODIES.

In short, no rule in prospecting for carnotite can be given, except as good judgment might be shown in choosing a favorable situation, and then the actual location of an ore body required at least two or three days and often several weeks of continuous work. The nature of this discovery work depended naturally on the topography and the probable depth of the ore-bearing horizon. On the Maggie C the ground sloped gently from a ridge into a gulley, and the ore, which as a rule dipped slightly more than the surface of the hillside, was 6 inches to 12 feet below the surface. On the higher ground removing a few inches of soil in many places uncovered the ore, which was found literally at the grass roots. Farther down the slope shallow pits, often supplemented by trenches, were dug. At still greater depths shafts were sunk 8, 10, or even 12 feet, and tunnels were driven into the face of the gulley to reach the ore from below.

On the Florence and Nellie claims, where the ore was near the surface, shallow pits and trenches were dug. Sometimes where the surface soil was a foot or so in depth a heavy steel bar pointed at one end and having a hook at the other was driven down to bedrock with a sledge and then pulled up by means of the hook. A small charge of dynamite exploded in the hole loosened the surrounding soil and facilitated its removal. In the gulleys most of the prospecting was by small tunnels, about 4½ by 6 feet in cross section. In two instances, previously mentioned, these followed "bug holes" or channels in the

rock caused perhaps by a fossil tree trunk or a root, which had become filled with high-grade carnotite. In places the sandstone surrounding the hole was impregnated with carnotite, forming a good shipping ore, to a depth of 12 or 15 inches. In other places the surrounding sandstone was barren.

The Great Western claim covered a still more rugged hillside and a gulch, and much of the prospecting was by short tunnels. This claim, however, differed from all the others in that a considerable part of the ore was found at a depth of 3 to 8 feet in the partly eroded brecciated zone of a horizontal, or nearly horizontal, fault. This condition made prospecting uncertain, as pieces of ore were mixed indiscriminately with rock, sand, and clay, and there were no reliable indications. As the miners said, prospecting was like looking for potatoes in a potato patch without rows. In prospecting this part shallow pits or trenches were dug more or less at random.

On part of the Vanadite claim the ore occurred beneath the edge of a sandstone ledge from which the ground sloped abruptly. Here prospecting was by short tunnels, some driven through the talus on the slope and some into the exposed sandstone. The rest of the claim presented no special problems of prospecting.

TIME DEVOTED TO PROSPECTING.

The first table following shows the amount of time devoted to prospecting and assessment work on each claim in percentages of the total number of 8-hour man-shifts worked each month on the entire group of claims. An average of 14 per cent of the total time per month was spent in such work, the amount falling off appreciably in midwinter. On the four largest producers the averages follow in general the total production, except that more prospecting was done on the Nellie than on the Great Western, whereas more development work was necessary on the Nellie, owing to the topography.

The second table shows what percentage of the monthly number of shifts worked at each individual claim was spent in prospecting; it shows that relatively much less prospecting was necessary on the Maggie C, where the ore was fairly plentiful and reasonably well defined as compared with the Florence, Nellie, and Great Western, the other chief producers. This table shows which claims were steady producers and which were nonproductive, that is, where the month's work was spent in prospecting, such as the Dixie and the Uranite, and those on which the ore "came hard," as on the Henry Clay, Buckeye, and Vanadite. On the Medea two or three small pockets, varying greatly in quality, afforded fairly steady work for one man, thus necessitating relatively little prospecting. The figures in the table may be taken as typical for a small group of carnotite claims in the region under consideration.

Time spent in prospecting and assessment work on each claim, in percentages of total mining shifts per month for all claims.

Month.	Maggie C.	Florence.	Nellie.	Great Western.	Henry Clay.	Medea.	Buckeye and Noontime.	Dixie.	Vanadite.	Uranite.	Total.
1914.											
June	1.5	....	....	0.0	0.0	....	....	....	....	....	1.5
July	3.8	1.0	2.1	1.6	1.6	....	....	....	....	....	10.1
August	1.4	2.8	2.4	2.1	.6	1.1	....	....	....	....	10.4
September	.0	.0	.0	.0	.0	.1	0.0	....	0.6	....	.7
October	1.0	1.7	.2	.9	3.7	.0	3.1	2.3	3.4	2.1	18.4
November	3.2	3.0	1.0	2.7	....	....	....	3.8	.2	3.9	17.8
December	7.0	1.9	3.7	1.6	....	.0	....	....	2.7	.3	17.2
1915.											
January	3.8	1.5	3.1	.9	....	....	....	....	....	....	9.3
February	1.5	.1	1.2	1.1	....	....	....	....	....	....	3.9
March	2.1	.0	.0	.5	....	....	....	....	....	3.1	5.7
April	3.5	1.6	.6	4.0	3.2	.3	....	2.3	3.5	2.4	21.4
May	1.8	2.9	3.2	.0	....	....	....	2.0	1.9	....	11.8
June	4.8	3.3	6.6	3.1	2.3	....	6.0	1.1	....	....	27.2
July	8.1	3.7	1.9	1.3	.0	....	....	....	....	....	15.0
August	5.0	5.1	.0	3.4	.1	.5	....	....	....	....	14.1
September	5.1	9.8	5.7	1.6	.8	.2	....	....	....	....	23.2
October	3.4	7.8	4.8	.9	....	.0	13.2	....	....	....	30.1
Average	3.6	2.7	2.1	1.5	.7	.1	1.3	.6	.7	.7	14.0

Time spent in prospecting and assessment work on each claim, in percentages of total mining shifts per month for each claim.

Month.	Maggie C.	Florence.	Nellie.	Great Western.	Henry Clay.	Medea.	Buckeye and Noontime.	Dixie.	Vanadite.	Uranite.
1914.										
June	2.9	....	....	0.0	0.0	....	....	....	....	....
July	6.1	46.3	27.0	12.8	26.1	....	....	....	....	....
August	2.1	34.0	44.4	26.7	35.0	43.3	....	....	....	....
September	.0	.0	.0	.0	.0	6.2	0.0	....	100.0	....
October	1.7	28.2	13.3	16.6	76.6	.0	44.0	100	77.3	100
November	5.6	48.0	66.6	24.7	....	....	....	100	2.1	100
December	10.4	63.6	37.0	17.7	....	.0	....	....	55.5	100
1915.										
January	5.3	100.0	26.3	9.6	....	.0	....	....	....	....
February	2.1	1.0	21.1	10.3	....	.0	....	....	....	....
March	3.4	.0	.0	4.4	....	.0	....	....	....	100
April	6.5	10.1	100.0	35.3	97.3	18.1	....	100	100.0	100
May	2.7	28.2	58.1	.0	....	....	....	100	100.0	....
June	1.3	14.6	84.4	17.2	100.0	....	100.0	100	....	....
July	20.6	12.2	28.1	11.9	.0	.0	....	....	....	....
August	17.1	9.7	.0	60.1	2.6	9.1	....	....	....	....
September	23.4	18.0	61.4	40.0	20.0	.0	....	....	....	....
October	18.6	31.9	18.6	6.1	....	.0	100.0	....	....	....

CONDITIONS GOVERNING DEVELOPMENT.

The 11 claims leased by the National Radium Institute may be considered a normal group, as the Maggie C, an excellent producer, was not without rivals, and three of the claims showed no ore at all, the assessment work on these being conducted at a dead loss and continued only to fulfill the terms of the lease. This condition served to balance the proportionately large tonnage mined from the Maggie C. The table on page 40 shows that the Maggie C produced

67 per cent of the total sacks of ore mined, the actual figures for tonnage being approximately 66½ per cent. Some may consider this an undue proportion from one of a group of 11 claims, and thereby designate the Maggie C as exceptional.

However, if the Maggie C had not produced as freely as it did, more extensive work would undoubtedly have been done on the other leased claims. Although this claim was a splendid producer the ore did not come easily, for the development work probably exceeded that done on any other carnotite claim in the district. None of the Maggie C ore was of very high grade, much of it barely averaging 2 per cent U_3O_8, while 56½ per cent of it was from underground work, involving planning, uncertainty, and expense. On a large part of this claim, that is, the north side of the gulley and the flat beyond the ridge, no ore was found.

However, if the Maggie C and the three unproductive claims be eliminated and the Florence, Nellie, Henry Clay, Great Western, Medea, Buckeye, and Vanadite claims be assumed to form an average group, to produce from these seven claims quantity of ore equal to that produced from the 11, during a like period by the same number of men, would have required about 20 such claims. This estimate is, of course, hypothetical because, with more men at work on these claims, more development and hence a much larger output is to be expected. As the development of the carnotite district progresses it is probable that a number of claims as productive as the Maggie C will be discovered; in fact, several claims in this district have yielded a far larger tonnage than the average. The Joe Dandy, on the south rim of East Paradox Valley, the Cliff mine at Saucer Basin, and the Last Chance, in the Hydraulic region, with their deposits of high-grade ore, are ample proof that claims yielding a large output of carnotite are not exceptional.

In general, however, the investor in carnotite mines should remember that a few scattered claims will not insure the continuous or sufficient ore supply necessary to run a radium-extraction plant or even to conduct a paying mining proposition. At least 20 claims, carefully chosen, will be necessary for a safe investment. Also the fact that a claim shows an outcrop or adjoins a known producer is not conclusive proof of its excellence, as the deposits are not continuous, nor can their depth in any instance be predicted. Careful prospecting and development work, with a rough outlining of possibilities and some idea of eventualities, should precede the purchase.

DEVELOPMENT.

Prospecting comprised searching for indications of ore and following these by open cut, churn drill, or other means. Development included following a lead of low-grade ore until it developed into a work-

able body of ore, delimiting the ore body to determine its possibilities, or, sometimes, driving a tunnel or open cut toward a known body of ore otherwise inaccessible.

When the ore lies at or near the surface, as on two or three of the Long Park claims, it can be easily and cheaply opened by means of pits, shallow shafts, or open cuts. The working place being well lighted, it is possible to drill and blast more effectively by taking advantage of changes of direction and quality, and the preliminary sorting of ore from waste can be made with greater accuracy. It is almost impossible to sort carnotite ore by artificial light, for reasons which are explained later. Where the amount of cover was too great to permit economical removal, mining had to be underground, and although excavation was somewhat more difficult, the protection of the miner from the weather and the fewer interruptions to work offered some advantages. During midwinter in Colorado and Utah the frozen ground makes surface mining impracticable, and one of the objects of development was to open in the fall suitable underground places for winter work.

With surface mining there is less need of development, because the miner can follow and delimit the ore more easily and handling waste rock is simplified. However, some development work is necessary to determine the disposition of waste (in order to avoid covering up possible ore bodies) and to minimize the handling of waste and ore. To this end, in open-cut work, development cuts wide enough for a wheelbarrow, or on the Maggie C a mine car and track, were driven along one side of the ore body. Waste could then be piled against the barren side of the cut and the cut widened until the other side of the ore body was reached. This method saved rehandling waste or tramming it an unnecessary distance. In mining a large ore body, as on the Maggie C, auxiliary open cuts were dug at intervals sufficient to provide working places, and a fan-shaped track system was laid. With the ore body thus defined, the handling of waste was simplified and to some degree the irregular character of the ore deposit overcome. All work driven along the side of the deposit, whether in a trench or underground, was called development unless such work produced a normal amount of shipping ore—that is, approximately 200 pounds per man per shift.

Underground development work was required in order to limit the ore body, to provide more working places, and also to provide for the advantageous handling of waste. Another and even more important factor in underground work is the greater cost of mining in narrow work while driving the tunnels as compared with that of stoping ore blocked out by tunnels on two or more sides. The cheapness of the latter method well repaid driving a system of devel-

opment tunnels and crosscuts wherever the ore body proved to be of noteworthy size or importance.

One feature of the development work which was of especial advantage on the Maggie C, and was used on the other claims where conditions were favorable was driving raises from various points underground to the surface to insure good light and air. This method, where the distance to the surface is not more than 8 to 12 feet, has many advantages. The better air enables the men to work to the best advantage, the time required for the smoke to clear after blasting is reduced to the minimum, and most important of all, the preliminary sorting of the ore can be done accurately and quickly and at the working place. Experience has demonstrated that time spent in such development work was repaid many times.

OPEN-CUT AND TUNNEL WORK COMPARED.

Choice must frequently be made between open-cut and drift in opening or developing a lead of low-grade carnotite ore. It is, of course, impossible to establish arbitrarily a definite point at which the open cut is preferable, but experience has shown that the drifting or tunneling is usually preferable wherever the overburden is more than 5 feet thick. At times, however, a tunnel is advisable when the overburden is thinner, as, for instance, when the waste must be carried far or the overburden forms naturally or through freezing a satisfactory roof. Obviously, expensive work such as tunneling should not be undertaken without more than an even chance of its developing enough ore to pay expenses at least. Hence in the course of the work described in this chapter, development tunnels were never started except to drive, usually through barren rock, to a body of ore that had been located by prospecting from shafts or pits, or to follow "bug holes."

The following table shows the cost of driving a tunnel on the Maggie C claim through barren sandstone to reach an ore body discovered by a test pit. This tunnel, which was 49 feet long, averaged 4 feet 2 inches wide and 6 feet 2 inches high. Two men were employed during the day and one man part of the time at night. The waste was wheeled in barrows 15 to 40 feet from the entrance. A slip or joint-plane in the rock, which was followed along one side of the tunnel for the entire length, was of much advantage in blasting. A comparison of the figures for driving through barren sandstone with the figures in the table at the bottom of page 26 shows the lesser cost driving in ore.

Cost, exclusive of overhead charges, of driving development tunnel in barren sandstone on Maggie C claim.

[Tunnel 49 feet long, 4 feet 2 inches wide, and 6 feet 2 inches high.]

Item.	Cost per linear foot.	Cost per cubic foot.	Total cost.
Foreman	$0.51	$0.018	$25.00
Mining	2.94	.105	144.00
Mucking	1.44	.052	70.50
Blacksmithing	.47	.017	23.19
Candles	.05	.002	2.55
Powder	.79	.028	38.48
Fuse	.09	.003	4.47
Caps	.07	.003	3.57
Total	6.36	.228	311.76

Instances of tunnels driven along "bug holes" are the main tunnel on the Florence claim, where the small amount of ore removed just about paid expenses until the larger pocket was encountered, or those on the Maggie C claim, driven through milling ore too low grade for sacking and shipment, but giving promise of leading to a pocket of shipping ore. The table following shows the cost of driving such a tunnel 78½ feet, average width 5 feet 9 inches, mean height 5 feet 10½ inches. One miner did the drilling and blasting, although part of the time another man was employed shoveling up the débris, and wheeling it in a barrow to the mouth of the tunnel and tramming it by mine car about 175 or 200 feet to the dump. The tunnel was driven for the most part through milling ore, but near its end a pocket of shipping ore was discovered and mined.

Cost of driving mining tunnel on Maggie C claim.

[Tunnel 78½ feet long, 5 feet 9 inches wide, 5 feet 10½ inches high.]

Item.	Cost per linear foot.	Cost per cubic foot.	Total cost.
Foreman	$0.199	$0.0059	$15.62
Mining	2.427	.0718	190.50
Mucking	1.146	.0339	90.00
Blacksmithing	.223	.0066	17.50
Candles	.027	.0008	2.15
Powder	.266	.0079	20.90
Fuse	.042	.0012	3.30
Caps	.035	.0010	2.75
Total	4.365	.129	342.72

From four of the five best producing deposits, two on the Maggie C and one each on the Florence and Great Western, most of the ore was mined by tunnel and stope, and approximately 60 per cent of the total production was from underground work.

TIME SPENT IN DEVELOPMENT WORK.

TOTAL TIME.

The writers found that about 12 per cent of the total time spent on all mining operations was profitably employed in development. This is an average for all claims, the figures varying from a negligible quantity on claims where no ore was discovered to 8.4 per cent on the Maggie C, where the development work was most thorough and systematic. To this must be added the time spent in mining milling ore and charged to the mill account. This work sometimes served as development by discovering or opening up pockets of shipping ore. Comparison of the following table with the table of ore produced by each claim (see p. 40) shows a relation between development and production that deserves serious consideration.

Percentages of entire mining time spent in development work.

Month.	Maggie C.	Florence.	Nellie.	Great Western.	Henry Clay.	Medea.	Buckeye and Noontime.	Dixie.	Vanadite.	Uranite.	Total.
1914.											
June	3.8	....	....	0.0	0.0	....	....	....	....	....	3.8
July	12.8	0.4	0.8	2.5	.5	....	....	....	....	....	17.0
August	5.0	1.6	.9	3.3	.2	0.0	....	....	....	....	11.0
September	.0	.0	.0	.0	.0	.0	0.0	....	0.0	....	.0
October	11.1	2.9	1.4	2.1	.8	.2	.3	0.0	.1	0.0	18.9
November	12.4	1.8	.4	1.9	....	....	....	.0	1.3	.0	17.8
December	11.2	....	.5	2.5	....	.0	....	....	1.6	.0	15.8
1915.											
January	13.5	.0	1.7	4.1	....	.2	....	....	....	....	19.5
February	8.6	.0	.4	3.6	....	.8	....	....	....	....	13.4
March	7.1	.0	.0	3.9	....	.6	....	....	....	.0	11.6
April	13.0	.6	.0	1.4	.0	.0	....	.0	.0	.0	15.0
May	17.6	.4	.5	3.6	.0	....	....	.0	.0	....	22.1
June	5.5	.9	.0	.6	.0	....	.0	.0	....	....	7.0
July	3.2	.6	.0	.9	.4	.2	....	....	....	....	5.3
August	3.2	1.3	.0	.0	.3	.2	....	....	....	....	5.0
September	2.9	5.1	.4	.0	.2	.2	....	....	....	....	8.8
October	3.5	1.3	2.2	.4	....	.0	.0	....	....	....	7.4
Average.	8.4	1.0	.5	1.9	.15	.14	.01	....	.2	....	12.0

TIME SPENT ON EACH OF THE VARIOUS CLAIMS.

The following table shows the percentage of the actual working time spent each month in development work on the different claims. On the Great Western, laid on a hillside, the ore bodies were usually small and irregular and relatively more time was spent in development than on the Nellie. The relatively extensive development on the Vanadite uncovered chiefly milling ore. On the Nellie low-grade ore was widely distributed, but no large body of shipping ore was uncovered. The Maggie C (see Pl. II, p. 14) was the most extensively developed, being opened on three levels, by open cuts, stope, and tunnel.

Percentages of total time spent in development work.

Month.	Maggie C.	Florence.	Nellie.	Great Western.	Henry Clay.	Medea.	Buckeye and Noontime.	Dixie.	Vanadite.	Uranite.
1914.										
June	7.3	....	....	0.0	0.0	....	....	....	....	....
July	20.4	19.5	10.4	19.5	8.3	....	....	....	....	....
August	7.0	19.6	16.9	42.3	10.0	0.0	....	....	....	....
September	.0	.0	.0	.0	.0	.0	0.0	....	0.0	....
October	17.7	46.9	71.1	37.9	1.7	25.0	3.6	0.0	18.9	0.0
November	21.2	26.6	22.2	17.7	....	....	....	.0	15.6	.0
December	16.4	.0	4.6	27.0	....	.0	....	....	13.3	.0
1915.										
January	18.7	.0	14.1	42.6	....	12.0	....	....	....	....
February	12.2	.0	6.5	33.5	....	16.6	....	....	....	....
March	11.3	.0	.0	34.3	....	12.5	....	....	....	.0
April	24.2	3.9	.0	12.9	.0	.0	....	.0	.0	.0
May	26.5	3.6	8.5	43.2	....	....	....	.0	.0	....
June	14.8	3.9	.0	3.7	.0	....	.0	.0	....	....
July	8.0	1.9	.0	7.7	10.0	4.8	....	....	....	....
August	11.3	2.4	.0	.0	10.2	3.0	....	....	....	....
September	13.6	9.4	4.6	.0	20.0	2.7	....	....	....	....
October	19.2	5.4	8.4	.3	....	.0	.0	....	....	....

REMOVING ORE.

All work incidental to the mining of shipping ore, its sorting, and preparation for shipment is included under "removing ore." In carnotite mining the waste rock and the ore are always removed separately, to prevent the mixing of ore and waste, and to obviate the shattering of the ore, and consequent loss of carnotite, by the heavier charges used in blasting rock. For this reason the two operations constitute separate, though related, problems. On the Maggie C claim, because of the number of miners employed and the quantity of ore produced, the workmen could specialize on definite types of work and the data could be kept in more detail. The following table shows the proportion of time required at this claim for the various mining operations included under "removing ore," such as mining and sorting the ore, and filling, sewing, and piling sacks.

Detailed data for Maggie C claim showing percentage of entire mining time spent in various operations.

	Per cent of total time.
Prospecting	7.6
Development	14.7
Stripping	19.8
Mining	24.0
Mucking	17.6
Sorting	7.9
Sewing sacks	2.6
Filling sacks	.7
Laying track	.8
Packing and loading	.5
Piling sacks	.3
Picking dump	2.8
Miscellaneous	.6

The work in mining carnotite falls naturally into two classifications: Surface work and underground work. Surface mining at the claims of the National Radium Institute consisted usually of gradually enlarging, as the ore body was followed, the pits or trenches; the underground work consisted of tunneling and stoping. In both classes of work the drilling and blasting methods were much the same, although of course more simple in surface work than underground. Also, as the preliminary sorting of waste rock from ore was much more difficult underground, it was almost always necessary to bring the ore to daylight before sorting it.

DRILLING AND BLASTING.

In all carnotite mining hand drilling is employed exclusively. On the claims of the National Radium Institute each miner drilled and blasted his own holes. The single-jack or striking hammer used weighed about 3½ pounds and had two striking faces; the handle was about 14 inches long.

The drills were made of octagonal steel. At first, ⅞-inch steel was purchased. It gave excellent results, but subsequent tests showed that $\frac{13}{16}$-inch steel was just as durable and efficient, and had the advantages of lower first cost and easier transportation from the blacksmith shop on the Maggie C to the other claims. Both sizes of steel were sharpened to a chisel edge. Usually the steel was cut into four lengths: Starters 18 inches, seconds 24 inches, thirds 30 inches, and fourths 36 inches, although for deeper holes drills 48 and 60 inches long were sometimes made. The gage of cutting edge for each length was the same for both weights of steel, that of the starters being 1¼ inches, seconds 1⅛ inches, and thirds and fourths 1 inch.

Drill holes were ordinarily 2 to 2½ feet deep. The sandstone varied in hardness, and the rate of drilling the waste rock was governed largely by its hardness and the presence or absence of black vanadium ore. Milling or low-grade ore was usually softer than the waste and the shipping ore was invariably softer than either. The average speed of drilling in waste rock was 37 inches an hour, in milling ore 42 inches an hour, and in shipping ore the rate was slightly more. In surface work the rate of drilling naturally averaged slightly higher than in underground.

The placing and direction of the holes were governed by the conditions at the working face, advantage being taken of any "slips" or joint planes or of any benches or other free surface left from a previous blast. Even in the tunnel work any fixed arrangement or round of holes was not practicable, though usually possible in other mining. Carnotite ore is so friable that the minimum shock that will loosen the ore is desirable, in order to prevent finely broken ore

being lost in the débris, and the hand drilling permits much greater elasticity of arrangement than the use of machine drills. On the average, two holes per shift per man were sufficient to shatter and loosen the shipping ore so that it could be broken down and removed. In the underground work blasting was usually done either at noon or at the end of the day, in order to permit the smoke to clear with the least possible loss of time by the miner. In blasting ore, after the drill holes were finished and before they were loaded, the floor for some distance from the face was carefully cleaned of waste, and was then either swept with a broom, or a sheet of canvas was laid on it to catch the fine soft material which was most valuable and most easily lost.

EXPLOSIVE AND FUSE USED.

All blasting was done with gelatin dynamite of 40 per cent strength. No experiments were made with dynamite of other grades because of poor results obtained with both 60 per cent and 30 per cent strengths elsewhere. The average charge in mining shipping ore varied from three-fourths to one stick per hole, according to the quality of the ore; in blasting waste the charge was one and three-fourths to two sticks per hole; in prospecting and development work the average was sometimes higher. White-finished gutta percha fuse was used. Some difficulty was experienced during the winter months in persuading the miners that cold fuse should not be handled roughly and should be warmed before being uncoiled for use. The amount used per hole varied, but the minimum length permitted was 2 feet, as nearly as the miner could estimate. No. 6 detonators were found much superior to No. 5 detonators in lessening the number of missed holes and increasing the breaking power of an equal charge of dynamite.

SORTING AND SACKING.

After blasting, and, if underground, close inspection of the roof, the scattered pieces of shipping ore were carefully collected by the miner and placed in a pile, any stray pieces of waste were thrown into another pile, and the low-grade ore or milling ore into another. The miner then removed with pick and gad all ore and rock loosened by the blast. This material received a preliminary sorting. In surface work, and in underground places sufficiently near a raise for good illumination, three products were made: Shipping ore, milling ore, and waste. Where the light was poor the material was separated into only two grades, ore and waste, the former being taken to the sorting table and there separated into shipping and milling ore. On claims where the number of men employed made it practicable, the shipping ore from the preliminary sorting was taken in

empty powder boxes, wheelbarrows, or mine cars to the sorting table, where another workman made the final sorting for shipment. On claims where only one or two men were employed the miners who, of course, had sufficient experience sorted the ore for shipment and put it in the sacks, which they sewed at convenient times

ILLUMINATION.

Various experiments were tried to discover some means by which carnotite ore could be distinguished underground. The usual method of illumination in the workings was the ordinary miner's candle. By candlelight the yellow color of the carnotite could be differentiated only with great difficulty from the white or gray parts of the barren rock, as well as from the dark vanadium ore with which it usually occurred, making it practically impossible to do even preliminary sorting. Acetylene lamps gave better illumination, but did not make sorting appreciably easier, nor did a hand electric flash lamp with a tungsten filament nor an incandescent mantle gasolene lamp. Therefore the use of candles was continued, and where possible the ore was opened in such a way as to permit all sorting to be done by daylight. Where daylight could not possibly be obtained near the working face, by driving a raise or otherwise, the ore had to be carried to it.

TIMBERING.

Little timbering was required in the tunnels, owing partly to their being narrow (usually not more than 4½ or 5 feet) and partly to the roof being solid. In the stopes the roof was supported with pinon posts cut from growths near the workings by the miners as needed, or cut by a man detailed for this purpose and hauled to the claim by team. As the timbers were unseasoned and the bark was not removed, they were liable to decay more rapidly, but owing to the short time they were needed this consideration was not serious. Most of the worked-out stopes were promptly filled with waste rock. The posts used averaged about 8 or 10 inches at the butt and were spaced more or less irregularly as required, but the average in most of the stopes was 4 or 5 feet apart. A view in one of the stopes is shown in Plate IV, *A*.

TIME SPENT IN REMOVING ORE.

TOTAL TIME.

The following table shows what percentage of the total monthly shifts, for the entire group of claims, was spent in removing ore. Approximately one-third of the total work was spent in such operations, and 60 per cent of this time was employed on the Maggie C

claim. By comparing this table with the one on page 40, showing the production from the various claims, the analogy will be seen to be striking. In other words, the presence and the nature of the ore body having been established by prospecting and development, the mining of the ore required a certain proportion of the total time worked, which parallels closely the tonnage produced, claim for claim, except on those claims where, owing to the irregular character of the ore deposit, the results of mining operations were necessarily uncertain.

Time spent in removing ore on each claim, percentage of total mining shifts for the group of claims.

Month.	Maggie C.	Florence.	Nellie.	Great Western.	Henry Clay.	Medea.	Buckeye and Noontime.	Dixie.	Vanadite.	Uranite.	Total.
1914.											
June	36.4	....	....	10.7	14.5	....	....	....	....	....	61.6
July	26.9	0.8	3.8	7.8	2.6	....	....	....	....	....	41.9
August	37.3	2.6	1.4	1.6	.7	1.1	....	....	....	....	44.7
September	33.4	1.7	1.2	5.5	1.7	1.1	3.6	....	0.0	....	48.3
October	24.0	1.0	.1	1.3	.2	.3	2.6	0.0	.5	0.0	30.1
November	18.8	1.5	.1	3.0	....	....	....	.0	3.2	.0	25.6
December	22.2	.5	2.7	2.5	....	.0	....	....	.2	.0	28.2
1915.											
January	20.2	.0	3.6	2.2	....	.7	....	....	....	....	26.7
February	29.3	2.0	1.6	2.9	....	1.8	....	....	....	....	37.6
March	23.6	5.3	.5	3.4	....	2.5	....	....	....	.0	35.3
April	13.1	5.7	.0	2.8	.1	.7	....	.0	.0	.0	22.4
May	17.4	3.1	.6	3.1	....	....	....	.0	.0	....	24.2
June	14.4	8.6	.4	6.9	.0	....	.0	.0	....	....	30.3
July	10.7	10.3	2.0	4.2	1.0	1.7	....	....	....	....	29.9
August	7.4	15.0	.1	.9	.7	2.2	....	....	....	....	26.3
September	4.4	12.7	2.3	.3	.0	3.3	....	....	....	....	23.1
October	3.7	6.7	9.3	6.7	....	.4	.0	....	....	....	26.8
Average	20.2	4.5	1.7	3.8	1.2	.9	.4	.0	.2	.0	33.0

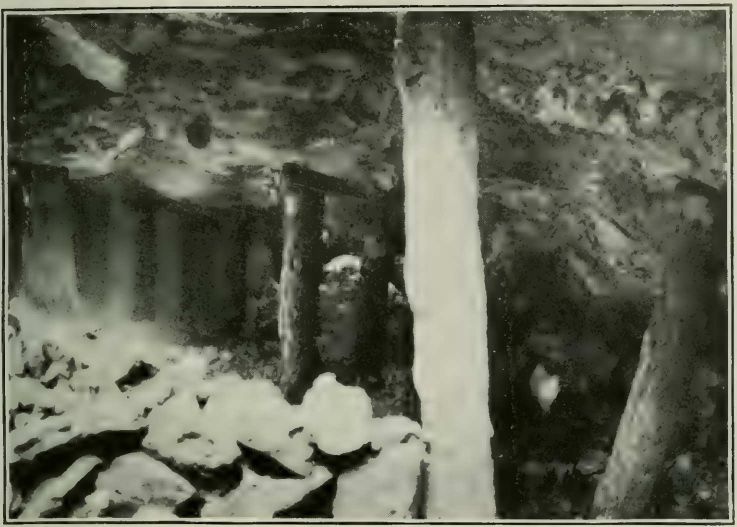
PRODUCTION.

The tonnage mined during each month of the first year and a half of the work, 1914–15, and the number of shifts spent in order to obtain such tonnage, are shown in figure 2.

The average number of sacks of ore produced per man per shift from each claim was as follows:

Average number of sacks of ore produced per shift by each man employed.

Maggie C	3.70
Florence	2.78
Nellie	2.30
Great Western	2.76
Henry Clay	1.68
Medea	4.07
Buckeye and Noontime	1.59
Vanadite	1.72
Dixie	.00
Uranite	.00
Average sacks per shift	3.21



A. STOPE IN A CARNOTITE MINE, SHOWING TIMBERING AND FILLING WITH WASTE ROCK.

B. SACKED ORE READY FOR LOADING AND SHIPMENT.

TIME SPENT ON EACH CLAIM.

The percentage of the work done each month on each individual claim that was spent in removing ore is given in the table following. This table shows which claims were not producers and explains the relation one to another of the development of the several claims. A comparison of this table with those giving similar figures for prospecting and development (see pages 22 and 27) shows the progress of the work.

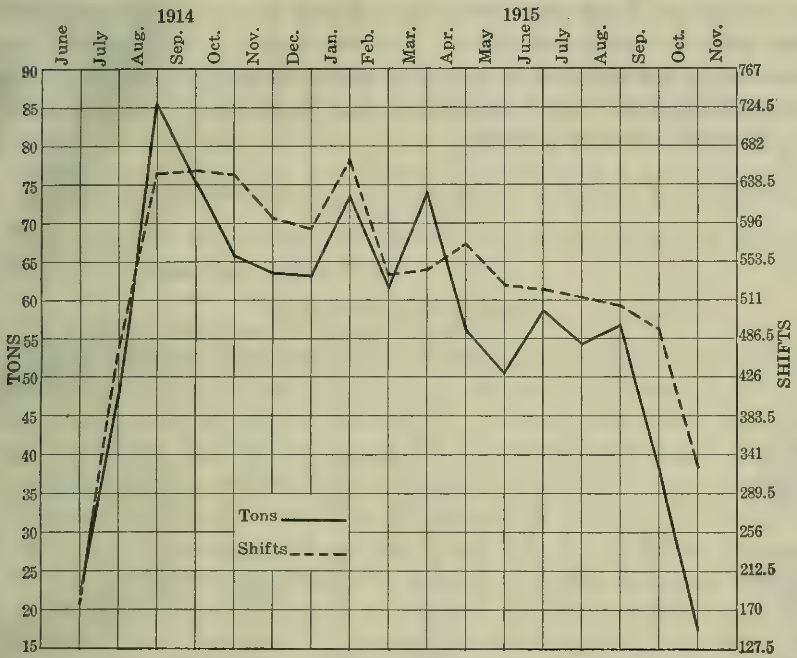


FIGURE 2.—Curves showing tonnage mined at the claims during 1914 and 1915, and number of shifts spent in mining.

Time spent in removing ore, per cent of total monthly time per claim.

Month.	Maggie C.	Florence.	Nellie.	Great Western.	Henry Clay.	Medea.	Buckeye and Noontime.	Dixie.	Vanadite.	Uranite.
1914.										
June	68.8	....	....	93.3	95.0	....	....	....	....	....
July	42.8	34.1	47.2	57.6	37.0	....	....	....	....	....
August	52.3	31.4	25.4	20.9	40.0	43.4	....	....	....	....
September	47.0	37.9	32.0	72.4	46.6	42.1	65.4	....	0.0	....
October	38.0	17.2	8.8	24.2	5.9	50.0	36.3	0.0	11.3	0.0
November	32.4	22.6	5.5	27.6	....	....	....	.0	36.4	.0
December	32.7	18.3	26.9	27.0	....	.0	....	....	37.0	.0
1915.										
January	28.9	.0	25.9	23.5	....	36.0	....	....	....	....
February	41.4	40.0	27.6	26.2	....	39.5	....	....	....	....
March	37.4	48.6	41.6	29.8	....	48.2	....	....	....	.0
April	24.2	35.5	.0	25.3	.3	36.3	....	.0	.0	.0
May	25.9	30.0	11.1	35.7	....	....	....	.0	.0	....
June	38.5	38.3	5.6	38.1	.0	....	.0	.0	....	....
July	27.0	33.7	30.8	36.7	25.0	41.0	....	....	....	....
August	25.9	28.6	24.0	16.5	23.0	38.6	....	....	....	....
September	20.7	24.8	25.0	12.5	.0	42.7	....	....	....	....
October	23.2	27.4	36.3	47.3	....	27.8	.0	....	....	....

DETAILED DATA ON MAGGIE C CLAIM.

Detailed figures on the various phases of the work of removing ore on the Maggie C are given in the table following. Under "mining" is included drilling and blasting in ore, and the preliminary sorting in the mine. "Sorting" consisted in breaking the larger lumps of ore brought to the sorting table by the miner and discarding any material of lower grade than 2 per cent U_3O_8. Sometimes the sorter filled the ore sacks, and sometimes another man did this work and also sewed the sacks and piled them near by. Where possible, the sacks were piled near the road (see Pl. IV, *B*), the object in piling being convenience in loading and to keep the sacks off the ground to prevent their rotting, the lowest row being laid on pieces of timber, as the ore absorbs moisture rapidly.

Proportions of time spent on Maggie C in various operations included under removal of ore.

Month.	Percentage of time spent in—					
	Mining.	Sorting.	Sewing.	Filling.	Piling.	Picking dump.
1914.						
June	15.2	13.0	4.4	1.4	(a)	39.1
July	25.7	10.0	3.0	(b)	(a)	7.1
August	43.0	9.2	2.3	(b)	(a)	....
September	40.1	6.9	2.6	(b)	(a)	....
October	28.7	7.7	2.8	1.7	1.2	....
November	23.0	8.2	2.8	.9	.9	....
December	22.9	8.1	2.7	1.6	(a)	....
1915.						
January	19.0	7.4	1.8	1.7	(a)	....
February	31.2	8.3	2.1	1.9	(a)	....
March	27.3	8.1	3.1	2.0	(a)	....
April	15.1	8.0	3.0	1.1	(a)	....
May	19.7	6.3	2.4	(b)	(a)	....
June	30.7	7.8	2.6	(b)	(a)	....
July	20.7	6.4	2.0	(b)	1.0	....
August	19.3	6.7	2.1	(b)	(a)	....
September	12.2	6.1	1.7	.2	.5	....
October	13.8	6.0	1.8	(b)	1.2	....
	24.0	7.9	2.6	.7	.3	2.8

[a] Included in sewing. [b] Included in sorting.

RESORTING OLD DUMPS.

During the first two months of operation at Long Park, a considerable part of the mining time was spent in resorting and picking over old dumps. In previous work the ore had been sorted to 3 per cent grade, leaving enough ore of 2 per cent grade to warrant resorting before covering with mill ore or waste.

REMOVING WASTE.

Removing waste included drilling and blasting waste rock and low-grade ore and removing them from the mine.

DRILLING AND BLASTING.

The drilling and blasting operations were, of course, practically the same as those employed in mining the ore, except that sometimes heavier charges of dynamite were used. Care had to be taken, however, to avoid mixing the waste with the ore or shattering the latter any more than necessary, for this caused losses of the best grade of carnotite, as has been previously mentioned. In surface work the soil, rarely more than a foot thick, was carefully removed before holes were drilled and blasted. Wherever possible advantage was taken of the bench formed by the previous blast. Underground the holes were pointed to break only the waste rock from above the ore. Both on the surface and underground the rock blasted was shoveled away from the immediate face. If the number of men working on a claim, as on the Maggie C, made such a course possible, a man was detailed to remove the waste to the dump, but on claims where only one or two men were employed the mucking was done by the miner before be began to remove the ore.

DISPOSAL OF WASTE.

The disposal of waste had to be varied on each claim to meet local conditions. In many places, where the ore was in small pockets at or near the surface, the waste was shoveled to one side, after it had been ascertained that no ore lay beneath. In mining the larger deposits the usual practice was to shovel the waste back into the excavation as mining proceeded. On the Maggie C a deposit of low-grade milling ore, of considerable extent, lying 4 to 6 feet below the shipping ore, could not profitably be mined with the shipping ore but was of sufficient importance to reserve for later use in the mill. Therefore from this area the waste was transported to a dump at one side, under which the ore lay too deep to be mined by open cut, by means of a fan-shaped track system leading to the various working places. The rock dump was gradually extended and built up level with the top of the ore bin of the mill, thus disposing of the waste and providing a grade for raising the milling ore into the bin when mined later.

In the underground work on this claim the waste was handled where possible by mine cars, both in driving the development tunnels and in mining. Wheelbarrows were used for the first 50 feet of the main tunnel and in one or two places in branch headings where the end of the track, owing to the pitch of the ore, could not be extended to the face of the heading. In stoping, as much as possible of the waste was immediately filled back into the stope to support the roof if the timbers failed and to save tramming this waste outside. On the other claims the waste was removed with wheelbarrows only,

with a plank runway where necessary, but was filled back into the stopes as much as possible.

The mine cars used on the Maggie C were of 13 cubic feet capacity, two being of the scoop type and two of the standard type with a swinging door at the end. Both types were provided with a turntable and could be emptied at either side of the track. For dumping from a trestle or into an ore bin, the scoop type was preferred, but for use on a track running along the edge of a dump the standard type gave better satisfaction. Ordinary 8-pound mine rails were used, set 18 inches apart on ties spaced about a yard apart, which were cut locally from small pinon. Long-handled, round-pointed No. 2 mining shovels were used to remove the waste, but in underground work the men usually cut 10 to 14 inches off the handle for convenience in narrow quarters. The wheelbarrows were of steel, with a rated capacity of 3 cubic feet.

TIME SPENT IN REMOVING WASTE.

The following table shows the percentages of the total time spent in removing waste:

Time spent in removing waste on each claim, percentage of total monthly shifts for the entire group.

Month.	Maggie C.	Florence.	Nellie.	Great Western.	Henry Clay.	Medea.	Buckeye and Noontime.	Dixie.	Vanadite.	Uranite.	Total.
1914.											
June	8.5	....	....	0.0	0.8	....	....	....	....	....	9.3
July	16.9	0.0	1.1	1.3	1.1	0.0	....	....	....	....	20.4
August	25.8	1.0	.3	.6	.3	.3	....	....	....	....	28.3
September	35.1	2.6	2.4	1.6	1.9	1.3	1.6	....	0.0	....	46.5
October	24.2	.4	.1	1.6	.2	1.3	.6	0.0	.3	0.0	28.7
November	21.0	.3	.1	3.2	....	....	....	....	3.4	....	28.0
December	23.7	.5	3.0	2.2	....	.0	....	....	.2	.0	29.6
1915.											
January	30.7	.0	3.6	2.2	....	.9	....	....	....	....	37.4
February	27.7	2.6	2.3	2.9	....	1.8	....	....	....	....	37.3
March	27.4	5.0	.6	3.6	....	1.9	....	....	....	.0	38.5
April	22.6	6.9	.0	2.5	.0	.8	....	.0	.0	.0	32.8
May	28.4	3.5	1.2	1.8	....	....	....	.0	.0	....	34.9
June	15.9	9.2	.7	6.1	.0	....	.0	.0	....	....	31.9
July	15.9	12.8	2.4	3.8	2.4	2.1	....	....	....	....	39.4
August	12.2	29.5	.4	1.1	2.1	2.5	....	....	....	....	40.8
September	8.6	24.7	.7	.3	.0	3.9	....	....	....	....	38.2
October	7.0	8.5	9.3	5.8	....	1.3	.0	....	....	....	31.9
Average	20.7	6.3	1.7	2.4	.5	1.1	.1	....	.2	....	33.0

The percentages of the total monthly work on each claim which were spent in removing waste were as follows:

Time spent in removing waste, percentage of monthly total per claim.

Month.	Maggie C.	Florence.	Nellie.	Great Western.	Henry Clay.	Medea.	Buckeye and Noontime.	Dixie.	Vanadite.	Uranite.
1914.										
June	15.3	....	....	0.0	5.0	....	....	....	....	....
July	27.7	0.0	12.5	10.1	18.5	....	....	....	....	....
August	36.9	11.9	5.3	8.1	15.0	13.3	....	....	....	....
September	59.9	58.3	64.1	20.5	51.1	50.0	28.6	....	0.0	....
October	48.4	70.3	4.4	15.1	3.3	25.0	8.9	0.0	7.5	0.0
November	35.6	4.0	5.5	28.8	....	....	....	0.0	39.6	.0
December	34.8	15.1	30.1	23.6	....	.0	....	....	3.7	.0
1915.										
January	42.5	.0	29.8	23.1	....	48.0	....	....	....	....
February	38.4	53.3	39.8	26.2	....	40.6	....	....	....	....
March	43.3	46.0	58.3	31.5	....	37.5	....	....	....	.0
April	42.0	43.3	.0	22.9	.0	40.9	....	.0	.0	.0
May	42.5	33.6	21.4	20.5	....	....	....	.0	.0	....
June	42.9	40.7	9.3	33.9	.0	....	.0	.0	....	....
July	40.1	40.9	36.0	32.9	60.0	50.9	....	....	....	....
August	42.4	55.9	72.1	19.5	61.5	43.9	....	....	....	....
September	39.9	45.4	7.9	12.5	.0	50.0	....	....	....	....
October	36.7	34.5	36.3	41.2	....	66.6	.0	....	....	....

The following table shows in detail the percentages of the monthly time spent on the Maggie C claim in various operations included in removing waste, such as stripping, mucking, and laying track:

Time spent on Maggie C claim in removing waste.

Month.	Percentage of time spent in—		
	Stripping.	Mucking.	Laying track.
1914.			
June	7.3	5.8	2.2
July	24.3	3.4	....
August	30.0	5.6	1.3
September	25.1	23.0	1.8
October	12.5	24.4	1.5
November	10.4	24.6	.6
December	16.2	17.9	.7
1915.			
January	20.1	20.3	2.1
February	24.1	13.2	1.1
March	30.8	11.7	.8
April	23.0	18.8	.2
May	15.7	25.8	1.0
June	13.4	29.4	.1
July	19.0	21.1	....
August	20.3	22.1	....
September	24.6	15.3	....
October	19.9	16.8	....
Average	19.8	17.6	.8

SORTING SHIPPING ORE.

DIFFICULTIES ENCOUNTERED IN SORTING CARNOTITE.

In sorting carnotite ore the sorters judge the ore rapidly, almost at a glance, solely from such physical characteristics as color, texture, and hardness. Unfortunately these three factors are extremely variable. Ore containing a high percentage of carnotite is a brilliant and unmistakable rich canary yellow; ores of shipping grade, those containing 2 to 3 per cent uranium oxide, are innumerable shades of orange, yellow, brown, green, or even black. Calcite, if present in quantity, makes the ore light yellow, almost white; copper makes it green; vanadium, usually green, although a large predominance may cause a lustrous dark blue, brown, black, or gray tint; calcium vanadate, claret colored; vanadic acid, brick red. Weathered ore is generally green or greenish yellow. As a rule ore of fine texture is of better grade than coarse sandy ore, although there are many exceptions. In such ore the carnotite, instead of coating the individual grains, as is usual with a coarse ore, and forming part of the cement, is in minute globules or specks often difficultly visible even under a powerful hand lens, or in small streaks or layers of almost pure carnotite. In general, the harder ores are poorer than those that are soft and friable, but on two claims, the Nellie and the Florence, some ore difficult to break with a heavy hammer contained as much as 3 per cent uranium oxide.

An efficient sorter must possess wide experience with carnotite ore, be able through long practice to judge rapidly and accurately the value of the ore; also he must have keen wits, for even an experienced sorter has many difficulties. On the claims at Long Park a yellow sandstone often met had the appearance, especially if at all wet, of good shipping ore but rarely contained more than 1 per cent uranium oxide. Closer inspection would show that the texture was coarse and that the specks in the sandstone had a duller and more orange hue than carnotite, and were, in fact, grains of yellow sand, the coloring matter being probably limonite or ocher. One variety of brown sandstone, about the tone of cocoa, that often carried as much as 5 per cent uranium oxide closely resembled another brown sandstone that was high in iron and contained little uranium. Careful comparison would show that the former had a yellowish tinge and specks of carnotite could be seen in it, especially under a lens, whereas the latter had a reddish hue; but the sorter has to make these distinctions at a glance. Another serious difficulty confronting the sorter is the wide variation in ores from different claims. For example, two specimens, one perhaps from the Maggie C and the other from the Florence or the Nellie, might be identical as regards color, texture, and hardness, yet the former would contain only 1 to

$1\frac{1}{4}$ per cent uranium oxide and the latter as much as $3\frac{1}{2}$ per cent. In other words, of two specimens of similar appearance procured from different claims, one may be only a milling ore and the other a good shipping ore.

The sorter must use judgment in determining the disposition of the fine material on the sorting table, some being produced by him in breaking the lumps to about 2-inch size for the sacks and some being brought to him in the ore. Generally this fine material is of better grade than the rest of the ore, because the higher grade ore is more friable, but sometimes the ore contains a quantity of fine waste, or, if much poor ore has been sorted a quantity of fine material not of shipping grade will be made. In either event the sorter must judge whether it is good enough to warrant sacking.

In winter the difficulties of sorting are greatly increased because the ore is frozen. The color of frozen ore is much less pronounced, the hardness is changed, and the ice crystals completely obscure the true texture. One remedy for this was to sort the ore in a small thawing shed heated by a stove. Any material left on the table at night was always covered with canvas and burlap.

When a sorter was being trained or was beginning work on a different claim or was in doubt he was urged to bring any doubtful specimens to the mine office to be tested in the electroscope for the uranium content. With these known samples to study, it was possible for him to sort more closely, easily, and surely. The miners were also encouraged to examine and compare such specimens and to bring in those of their own selection, which were also tested, to guide them in the preliminary sorting at the mine.

METHOD OF SORTING.

At many carnotite mines it is the custom to sort both the ordinary shipping ore and the high-grade ore in several grades. At the Long Park claims of the National Radium Institute so-called high-grade ore was discovered in such inconsiderable quantities that no separate classification were made, except on the Maggie C. The ore was therefore sorted to two grades only: milling ore, running from one-half to $1\frac{1}{4}$ per cent U_3O_8, and shipping ore, averaging about 2 per cent.

EQUIPMENT.

The sorting tables usually consisted of several 2-inch by 12-inch planks which were supported at the ends and the middle by 2-inch by 4-inch timbers laid on the ground. Similar planks were set edgewise around three sides of the table. On claims where the amount of ore in sight was small and only one or two men were employed the ore was often broken and sorted on a clean flat rock. (See Pl. V, *A*.) On the wooden table the ore was broken on a

cast-iron or steel plate, partly-worn jaw plates from the crusher serving for this purpose. For breaking the larger lumps or frozen ore the sorter used a 2-pound hammer provided with a square face and a chisel point. For the finer lumps he used an ordinary prospector's or geologist's pick, square-faced on one end and pointed on the other.

AMOUNT SORTED PER MAN.

The amount sorted in a day varied greatly. When the ore was of good quality the sorter had little else to do than break it to proper size for shipment and throw out any occasional piece of waste rock or low-grade ore. Under such conditions it was not unusual for one man to sort 75 to 80 sacks in one day. But when the ore was of poorer quality, and especially if shipping and low-grade ore were badly mixed, sorting was more laborious, requiring much closer attention and the handling of much more low-grade material. Under such conditions 25 to 30 sacks per sorting shift was a good day's work. The average number of sacks sorted on the Maggie C claim during the entire period of mining operations was 48.4 per 8-hour shift.

The following table gives the monthly production of sorted ore, that is, shipping ore, produced from the various claims:

Monthly production of shipping ore from the various claims, in sacks of approximately 70 pounds.

Month.	Sacks of ore produced on—										Total.
	Maggie C.	Florence.	Nellie.	Great Western.	Henry Clay.	Medea.	Buckeye and Noontime.	Dixie.	Vanadite.	Uranite.	
1914.											
June	459	1	....	151	31	....	....	....	....	......	642
July	846	....	158	253	100	....	....	....	....	......	1,357
August	2,040	87	127	76	49	59	....	....	....	......	2,438
September	1,516	63	77	219	64	58	153	....	....	......	2,150
October	1,587	97	11	38	19	10	54	....	72	......	1,888
November	1,487	78	6	98	....	....	....	....	155	......	1,824
December	1,534	13	162	77	....	....	....	....	20	......	1,806
1915.											
January	1,462	11	134	116	....	45	....	....	....	......	2,068
February	1,470	52	62	107	....	92	....	....	....	......	1,783
March	1,559	315	6	106	....	118	....	....	....	......	2,104
April	1,046	359	11	118	12	42	18	....	....	......	1,606
May	1,066	228	34	113	....	....	....	....	....	......	1,441
June	644	513	33	460	1	....	4	....	....	......	1,655
July	668	440	84	267	30	76	....	....	....	......	1,565
August	466	898	4	45	24	175	....	....	....	......	1,612
September	202	544	104	21	....	217	....	....	....	......	1,088
October (1-15)	128	84	177	111	....	8	....	....	....	......	508
Total	18,480	3,783	1,190	2,376	330	900	229	....	247	......	27,535

A. SORTING CARNOTITE ORE ON FLAT ROCK.

B. CONCENTRATING MILL AT LONG PARK, COLO., SHOWING SITE.

C. GRIZZLY ABOVE ORE BIN OF CONCENTRATING MILL, WHERE MILLING ORE WAS RESORTED.

FILLING, SEWING, AND PILING THE SACKS.

The sorted ore was pushed to one side and at intervals shoveled into sacks 18 by 24 inches in size and holding approximately 70 pounds of ore. Burlap sacks were tried at first, but were quickly discarded in favor of double-stitched canvas sacks. These resisted wear and tear well and saved fine material, which is usually high grade, that would have been lost through the wide mesh of the burlap. The canvas sacks, of course, cost more, but the fact that some of them could be used twice, and the saving of fine material, made them much more economical than burlap in the long run.

Where the output warranted the expense, the sorter was provided with an assistant, who filled the sacks, sewed them, and piled them. To facilitate filling the sacks, a rough funnel was made of a piece of fairly heavy galvanized pipe 8 inches in diameter and 2 feet long, with a flaring top forming an angle of about 30° with the pipe and enlarging the diameter to about 18 inches. The rim of this flaring part was turned under around a circle of $\frac{1}{4}$-inch iron rod to give rigidity and better wear. This filler held the sack open and kept it upright so that the ore could be shoveled in readily.

The sacks were sewed with a $5\frac{1}{2}$-inch curved needle and 16-fold cotton sail twine. The top of the sack was folded over twice, the twine being looped around one corner to form an "ear," and then sewed over and over, including the folds, until the other side was reached; a couple of half stitches formed the other "ear." The sack was then resewed in the reverse direction, two half stitches were taken around the first ear, and the twine pulled through the sack once more and the ends tied. An experienced man could sew 200 sacks in a day, the average for all claims being about 20 sacks an hour.

SAMPLING.

Before sewing a sack, a rough grab of ore, about a handful, was taken at random from it. When the sample from about 100 sacks had accumulated, it was broken by hand to approximately $\frac{3}{8}$-inch size and carefully quartered twice; the reject went with the shipping ore and the sample was brought to camp. It was then reduced on a cast-iron bucking board to perhaps $\frac{1}{8}$-inch pieces and quartered down to about a pound sample. This was ground on the bucking board and in a quart mortar to pass through a 30-mesh sieve, and then quartered twice, the resultant sample being tested in the electroscope.

WEIGHTS OF SACKS OF ORE.

The following table shows the average weights, each month, of the sacks of ore as they arrived in Placerville, where they were weighed, in the wagons, on a platform scale.

Average gross weight, in pounds, per sack of ore as weighed in Placerville, Colo.

Ore left Long Park in—	Maggie C.	Florence.	Nellie.	Great Western.	Henry Clay.	Medea.	Buckeye and Noontime.	Dixie.	Vanadite.	Uranite.
1914.										
August	74.7	....	....	74.8	76.2	....	....	....	....	....
September	72.9	....	75.7	77.8	....	62.5	....	....	....	....
October	72.0	76.5	73.0	78.9	68.2	....	71.2	....	....	....
November	72.0	74.6	....	69.0	....	....	....	....	....	....
December	76.6	....	67.6	....	67.5	68.3	....	....	67.0	....
1915.										
January	69.0	....	66.8	68.4	....	....	....	....	....	....
February	68.3	66.6	....	66.3	....	64.6	....	....	....	....
March	73.1	78.7	....	....	....	64.8	....	....	....	....
April	70.6	74.4	74.0	80.0	....	67.7	75.0	....	....	....
May	67.7	71.7	68.2	72.7	....	68.5	....	....	....	....
June	68.0	72.6	70.0	84.4	....	....	67.5	....	....	....
July	66.6	69.8	....	70.6	....	....	....	....	....	....
August	68.6	74.6	....	....	....	70.4	....	....	....	....
September	75.9	77.4	70.7	70.3	67.1	73.4	....	....	....	....
Average	71.2	73.5	71.2	74.6	71.4	68.5	71.4	....	67.0	....

Average gross weight per sack, 71.67 pounds.

The wide variations in these figures are doubtless due to many causes, such as the personal equation of the sorter, for although the sacks were of the same size some slight diversity in filling was possible. It was thought that the ore per sack would weigh heavier during the winter months, on the theory that the frozen ore contained more moisture. The difference in weight between a sack of ore containing 2 per cent moisture, as in summer, and one containing 7 per cent, as in winter, was not sufficient, however, from the record in this table, to increase the average appreciably during the winter months. The character of the ore on the different claims varied greatly. Some types of ore broke into fairly large pieces with very little fines, so that the air spaces in the sack made it much lighter than one filled with finely pulverized ore. In a few instances that can be traced from the records the weights on certain claims changed noticeably at about the same time that new workings were being opened, so it is probable that changes in the character of the ore were the main factor in this diversity. On the Florence and the Great Western, where the ore usually ran fairly high in U_3O_8, and therefore was apt to be rather finely pulverized, the sacks averaged the heaviest, whereas on the Medea and the Vanadite, where the uranium content was almost uniformly low, the sacks averaged lightest.

VARIETIES OF ORES ENCOUNTERED.

The shipping ore from the Maggie C claim was for the most part a more or less coarse-grained sandstone impregnated with carnotite, which usually formed the binder between the individual sand grains, having probably replaced the original cement. The individual

grains of this sandstone were often thinly coated with fine carnotite, which gave the ore the appearance of being better than it actually was. Another variety found in many places on the Maggie C, and to some extent on the Florence and Nellie, called locally "rattlesnake ore," was a coarse-grained sandstone containing small patches one-quarter to one-half inch in size impregnated with black vanadium oxide and with carnotite, both kinds of patches being scattered at intervals of perhaps one-half to three-quarters of an inch in seemingly barren sandstone. The patches of carnotite were too small to separate by sorting, and the entire mass generally ran too low in uranium content to be shipping ore, so this ore was sent to the mill. Another type mined on the Maggie C was the brown or cocoa-colored ore previously described, which usually contained more than the average percentage of uranium; but as a large amount of the low-grade reddish-brown ore, chiefly iron bearing, was also found there, careful sorting and frequent tests in the electroscope were necessary to prevent shipping ore of too low grade. Very little high-grade, fairly pure carnotite was found on this claim—or on any of the other claims—and that found was mostly in stringers, in "bug holes," or in tiny pockets that were not more than 2 inches thick at the most, although some were 4 or 5 feet long. When such high-grade ore was discovered, the quantity was usually too small to permit sorting as a separate grade, consequently it was thrown into the shipping ore. One or two of these "bug holes" of high-grade ore were large enough to warrant keeping the ore separate, two sacks being obtained in all.

Such shipping ore as was found on the Henry Clay claim was invariably high in vanadium and was usually greenish-yellow to greenish-gray. In this ore the texture was rather fine, and it usually occurred in a finely-banded sandstone. The ore from the Florence was also of this banded or bedded type, being generally rather high in vanadium. A number of tons of ore from one pocket on this claim showed this bedded structure very plainly, much of it consisting of fine bands about one-sixteenth of an inch thick, of nearly pure carnotite, lying in a soft, almost claylike mass of black vanadium ore. A number of small "bug holes" of high-grade ore were discovered and mined on this claim, but no attempt was made to create a separate grade.

Most of the ore from the Nellie claim, adjoining the Florence, was similar to that from the Florence, except that no black ore with streaks of high-grade carnotite was found. Ore similar to that on the Maggie C, containing sandstone grains coated with carnotite, also occurred, but most of it was of finer texture than that on the Maggie C, and as a consequence usually contained a higher percentage of uranium.

On the Great Western claim the ore commonly contained a rather high percentage of calcite, and consisted of a fine-grained rather high-

grade shipping ore and a coarse-grained milling ore running much lower in uranium oxide.

On the Vanadite claim the ore was rich in vanadium, usually containing streaks of vanadic sandstone impregnated with carnotite between bands of gray or white barren sandstone.

The ores on the Medea claim, with one exception, were greenish and were found in a banded finely grained sandstone. In the exception mentioned the ore was rather coarse grained, closely resembling that on the Maggie C, and contained thin stringers of calcium vanadate and vanadic oxide,[a] rarely more than half an inch thick, which generally crossed the bedding of the sandstone and seemed to be small fissure veins.

On the Buckeye and Noontime claims the ore contained a high percentage of vanadium and was greenish to blackish in color. Some specimens from these claims were especially rich in vanadium and carried 1 to 2 per cent uranium oxide; they had a shiny, metallic luster and a bluish-green color. Such ore is locally called kentsmithite or mcmillenite.

THE ELECTROSCOPE.[b]

Radioactive ores accelerate the rate of discharge of electricity from a charged body because the rays they give off ionize the atmosphere surrounding the charged body. Hence an electroscope can measure radioactivity. The electroscope used by the National Radium Institute at the mines consisted of two cylindrical compartments of brass.

The upper cylinder was about 3½ inches in diameter and was placed horizontally on the lower one, the ends being closed with mica windows to exclude disturbing air currents; the lower cylinder was placed vertically and closed at each end with a brass plate. Its lower face was flanged and screwed to a wooden base; on the upper face a short pipe supported the first compartment. A small brass rod, extending through a plug of sealing wax in this pipe that insulated the rod from the rest of the apparatus, was flattened at its upper end where it extended into the upper compartment and terminated at its lower end in a thin brass disk about 2½ inches in diameter, set at right angles to the rod and about half an inch from the top of the lower compartment.

Attached to the upper and flattened part of the rod and wholly within the upper compartment was a thin piece of aluminum foil 2 inches long and one-quarter of an inch wide, suspended from the top so that ordinarily it rested against the rod. When, however, the

[a] Hillebrand, W. F., Merwin, H. E., and Wright, F. E., Hewettite, metahewettite, and pascoite; hydrous calcium vanadates: Proc. Am. Phil. Soc., vol. 53, 1914, pp. 31–54.

[b] For a more complete description of the electroscope and electroscopic methods see: Moore, R. B., and Kithil, K. L., A preliminary report on uranium, radium, and vanadium, Bull. 70, Bureau of Mines, 1913, pp. 64–66; Lind, S. C., and Whittemore, C. F., The radium-uranium ratio in carnotite, Tech. Paper 88, Bureau of Mines, 1915, pp. 17–19; Lind, S. C., Practical methods for the determination of radium; interchangeable electroscope and its use, Jour. Ind. and Eng. Chem., vol. 7, 1915, p. 406.

leaf and rod were charged with electricity (generated on a vulcanite rod rubbed against wool or silk) the leaf was repelled from the rod and extended at an angle from it. If the instrument were then left undisturbed the leaf would very slowly fall to its former position as the charge gradually leaked away. The rate of this fall (observed through a microscope attached to the apparatus by means of a brass arm), measured by a stop watch in terms of the divisions on a scale in the eyepiece of the microscope, was termed the "natural leak" of the instrument. If the leaf were again charged and a quantity of carnotite put in the bottom compartment through a door provided for that purpose, the rate of fall would increase.

The rate of such fall is, within reasonable limits of accuracy for a field test, always proportional to the amount of uranium oxide in the carnotite. Therefore, if this sample of ore be removed and the same quantity of a standard ore of known uranium content be put in the machine and the rate of fall of the leaf be again measured, the uranium oxide content of the sample can be computed by the following formula: (Rate of fall with sample minus rate of natural leak) : (Rate of fall with standard minus rate of natural leak) : : (Per cent U_3O_8 in sample) : (Per cent U_3O_8 in standard).

PRECAUTIONS IN USING ELECTROSCOPE.

In using the electroscope several precautions are necessary, perhaps the most important of which is to have the ore ground to the same fineness. Experiment has shown that the influence the ore exerts, and hence its apparent uranium content, varies greatly with the fineness of the ore. This error has been found to be as high as 100 per cent when comparing ore ground to pass a 200-mesh screen with similar ore passed through a 30-mesh screen, the finer material giving the lower result. For this reason the ore to be tested and the standard ore must be passed through the same mesh of screen, and it is obvious that in grinding the samples all of the material must be passed through the screen; otherwise, the lower-grade material being the harder, a partial concentration would vitiate the results. The screen used was about 30-mesh bolting cloth stretched on a wooden hoop, but 40-mesh or even 60-mesh screens could be used. The same screen should be used for both sample and standard, and should be thoroughly cleaned after each test. The quantity of ore, both standard and sample, placed in the electroscope should be constant.

The error resulting from using varying quantities of ore is not as great as that resulting from a wide difference in fineness, but is sufficient to destroy accuracy. For this purpose the electroscope used at the mines was equipped with a small brass disk, fitting into the bottom compartment, that had a raised rim about one-sixteenth of an inch high. When the ore was spread over this disk and any excess scraped off with a straight metal blade, such as a common

table knife, there remained a film of ore one-sixteenth of an inch thick and the diameter of the disk. Care was taken to have the surface left perfectly smooth in order to insure that the same amount was always retained on the plate. When testing finely powdered material, such as concentrates, the required smoothness was obtained by pressing the material down with the flat underside of a second disk, using a slight rotary motion. The plate was then carefully pushed through the door onto the floor of the lower compartment. As illumination on the leaf should be constant for both readings, it is usually more convenient to make the electroscopic tests at night and by artificial light, a candle back of the electroscope throwing the leaf into sharp silhouette.

PACKING, STORAGE, AND TRANSPORTATION OF ORE.

PACKING AND STORING ORE.

About 1 per cent of the total mining time was employed in packing and loading ore. The freighting of ore, which was done by team and wagon, was not begun until late in August, 1914. During the winter months the sacked ore from the Florence, Nellie, Great Western, and Vanadite claims was packed by a train of two to eight burros, two being owned by the company and the others hired from miners, to the warehouse on the Maggie C claim. The Maggie C ore was also stored there during the winter, and the freighters loaded from that point the shipping ore from the claims mentioned. Once, in December, 1914, it was necessary to pack the Medea ore to the main road with burros, but at other times the teams were able to load on the claim.

A table showing the amount of time spent in packing ore and loading follows.

Percentages of total mining time per month spent in packing ore and storing in warehouse.

Month.	Maggie C.	Florence.	Nellie.	Great Western.	Henry Clay.	Medea.	Buckeye and Noontime.	Dixie.	Vanadite.	Uranite.	Total.
1914.											
June	0.0	....	....	0.0	0.0	....	....	....	....	....	0.0
July	.0	0.0	0.0	.0	.0	....	....	....	....	....	.0
August	.0	.0	.0	.0	.0	0.0	....	....	....	....	.0
September	.1	.1	.5	.5	.0	.0	0.0	....	0.0	....	.75
October	.0	.04	.04	.3	.0	.0	.6	0.0	.0	0.0	.98
November	.0	.0	.0	.09	....	....	....	.0	.36	.0	.45
December	1.8	.09	.14	.36	....	.05	....	....	.18	.0	2.62
1915.											
January	1.9	.0	.2	.1	....	.0	....	....	....	....	2.2
February	2.06	.14	.3	.4	....	.0	....	....	....	....	2.9
March	.8	.3	.0	.0	....	.0	....	....	....	....	1.1
April	.04	.6	.0	.36	.0	.0	....	.0	.0	.0	1.0
May	.0	.19	.05	.15	....	....	....	.0	.0	....	2.9
June	.0	.2	.05	.25	.0	....	.0	.0	....	....	.3
July	.0	.66	.04	.0	.0	.0	....	....	....	....	.7
August	.0	.58	.02	.13	.0	.0	....	....	....	....	.73
September	.0	.10	.10	....	.0	.0	....	....	....	....	.20
October	.0	.22	.11	.33	....	.0	.0	....	....	....	.66
Average	.4	.2	.1	.2	....	....	....	....	....	....	[a]1.0

[a] Approximately.

TRANSPORTATION OF ORE.

The distance between the claims and the nearest railroad station, Placerville, Colo., was approximately 58 miles, and the teams made the round trip in seven days. Four or six horses hauled two wagons, one of them a trailer. Four-horse teams hauled $3\frac{1}{2}$ to 4 tons of ore; the six-horse teams 5 to $5\frac{1}{2}$ tons. As Long Park is isolated, all commissary, mine, and mill supplies, including lumber, machinery, etc., were hauled from the railroad station at Placerville or intermediate points. Usually the freighters who hauled the ore loaded the wagons, but frequently were assisted by miners detailed for this work. At Placerville the ore was unloaded into the warehouses rented by the institute, or loaded direct into the railroad cars, which were narrow-gage cars holding approximately 35,000 pounds each. Two cars were shipped at one time, and were reloaded into one broad-gage car at Salida, Colo.

MISCELLANEOUS AND GENERAL WORK.

MISCELLANEOUS.

Under "miscellaneous work" the most important item was cutting and setting up mine timbers, but it also included making rough roads and trails and carting tools to the various workings, setting up and moving sorting tables, and similar unclassified work. Not more than half of 1 per cent of the total mining shifts was spent in these tasks. Roughly, half of the time under this item is directly chargeable to the Maggie C, one-fourth to the Florence, one-tenth to the Great Western, and the rest to the other claims.

GENERAL EXPENSE.

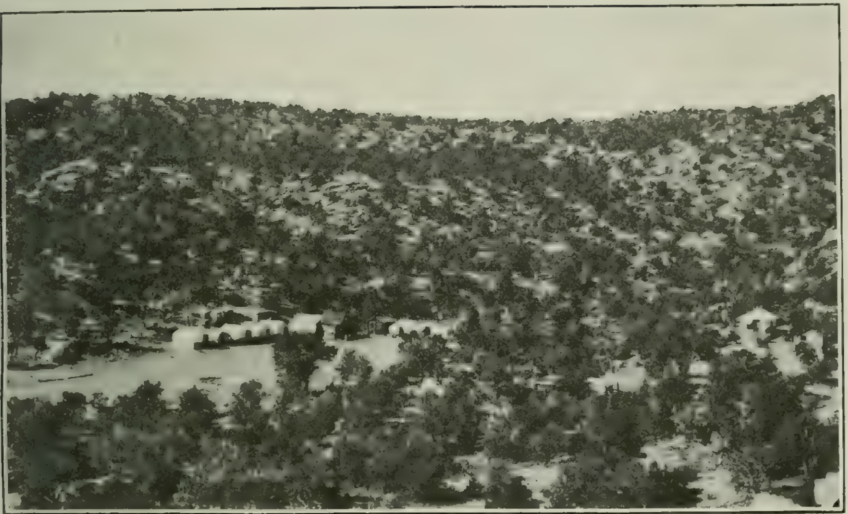
Under the caption "general expense" were included items incidental to mining, but not directly chargeable to any one claim in particular. Chief among these is blacksmithing. Approximately 4 per cent of the total mining time was charged to the "general" account, which included, in addition to blacksmithing, such items as making tool boxes, repairing blacksmith shop, constructing powder magazine and warehouse, grinding samples for electroscopic tests, overtime for loading wagons, etc. The blacksmithing time, rightly chargeable to the mine account, averaged a little less than half a shift daily, or something under $2\frac{1}{2}$ per cent of the total mining time. The item included sharpening drill steel and repairing tools, and also work in mill construction, laying track on the Maggie C (listed separately under the special table for that claim, see page 28), and camp repairs. The distribution of the blacksmith's time, based on the number of holes drilled per claim, is as follows: Maggie C, 50.5 per cent; Florence, 22.9 per cent; Nellie, 6.6 per cent; Great Western, 8.7 per

cent; Henry Clay, 2.6 per cent; Medea, 3.9 per cent; Buckeye and Noontime, 1 per cent; Dixie, 1.3 per cent; Vanadite, 1.5 per cent; Uranite, 1 per cent. An average of about eight steels were sharpened per hour of the blacksmith's time, at a cost of 3½ cents per hole blasted. The figures for the Buckeye and Noontime claims are low, because during the 1914 work on these claims the tools were sharpened by the miners.

Other work not included in the foregoing is the time of the mine foreman, which was distributed over the various claims as follows: Maggie C, 56 per cent; Florence, 11½ per cent; Nellie, 5½ per cent; Great Western, 11 per cent; Henry clay, 3½ per cent; Media, 2½ per cent; Buckeye and Noontime, 2¾ per cent; Dixie, 1½ per cent; Vanadite, 1¼ per cent; Uranite, 1 per cent; camp, 1½ per cent. These figures take into consideration the number of men at work on the claim during each month of the mining period, the distance of the claims from camp, the time necessary to make the circuit, and the fact that at times several workings were visited in one trip of inspection, and at others long rides were necessary to visit one isolated miner. The figure for camp includes supervision of the building operations, of repairs and general maintenance, and is rightly chargeable to commissary, but was inserted here to indicate the correct ratio.

COMMISSARY AND CAMP.

The distance of the mines from any town necessitated living quarters for the men, consequently a camp (see Pl. VI, *A*) was established at the extreme western end of Long Park, on the Maggie C mill site and convenient to a small spring. The kitchen, the foreman's office, and the guest house were frame buildings 10 by 14 feet in dimension. The mess room and the men's quarters were tents stretched over a frame made of 2 by 4 inch lumber, but provided with wooden floors and wooden sidewalls built up about three feet from the floor, where the tent walls were attached. The mess tent, 14 feet wide and 16 feet long, was placed at the rear of the kitchen building and connected with it by a door, another door gave access from the outside. The tent had windows on three sides, and contained two tables that could accommodate 30 persons. In cold weather it was heated with a wood-burning heating stove, in summer it was well screened. The men were housed in six 12 by 14 foot tents accommodating five men each, a similar tent being provided for the cook and flunkeys. The men slept in wooden bunks. In winter the wooden sides of the tents were covered with heavy tar-paper and banked with earth; airtight stoves made the quarters comfortable. Wood for these stoves was hauled to camp by team on the institute's time and piled conveniently for cutting. Each tent was equipped with a kerosene lan-



A. CAMP AT LONG PARK, COLO.

B. CLOSE VIEW OF CONCENTRATING MILL AT LONG PARK, COLO.

tern, a wash basin, bucket, and broom. The men were given individual canvas water bags for drinking water, which they took with them daily to work. For the superintendent a 10 by 14 foot "Colorado tent house" was furnished. The cook house, foreman's and superintendent's offices, and guest house were provided with gasoline lamps. In the fall of 1914 a telephone was installed.

The saddle horses, which numbered one to three during the work, were housed in a brush corral and a small frame stable. A chicken house adjoined the corral.

The National Radium Institute maintained its own commissary, charging the men $1 a day for board, and not seeking to make any profit from this charge. The food comprised canned goods and other provisions, fresh meat, vegetables, and fruit in season. A plentiful supply of pure water was always kept on hand, although during more than half of 1915 this had to be hauled daily by team from a spring a mile and a half distant. Two roomy cellars housed the provisions and kept them cool and dry; heavy double doors prevented freezing in winter. The meat house was thoroughly screened and sheltered.

Many of the men working on the more distant claims did not return to camp for the midday meal and a special attempt was made to have their lunches attractive and appetizing. As a result of the attention given to the commissary the men were satisfied, and changes in the personnel were infrequent. Of 19 men employed August 1, 1914, 13 were still on the payroll on October 1, 1915, fourteen months later. As breaking in new men to carnotite mining is expensive, because of their inefficiency for the first two weeks and the increased demands on the foreman in educating them to know the ore, the policy of allowing no grounds for dissatisfaction with the commissary paid splendid dividends, even though the department might be conducted at a slight loss. The superintendent ordered all supplies, buying monthly and in bulk by means of competitive bids, inventories being taken at intervals of not more than a month.

For amusements, through the kindness of Drs. Douglas and Kelly of the National Radium Institute, the men were provided with a baseball outfit and a croquet set. Some of the men played at bowling or "bocci." A phonograph was in the foreman's house, which also served the purpose of general club house and reading room. All gambling was forbidden.

SAFETY AND HEALTH PRECAUTIONS.

Mining for carnotite is less hazardous than many other types of mining, because the workings are relatively small and shallow and largely open to the day, and also because the miners must possess a rather high grade of intelligence. Safety in working conditions and

prevention of accidents received foremost consideration, the rule of "Safety first" being strictly enforced, as far as possible, and constantly impressed on the men.

The chief dangers were from possible falls of rock and the handling of explosives. Each miner was warned repeatedly to take time to make the roof safe, and always to examine the roof and the walls carefully after each blast. As the men were paid by the shift, there was no particular difficulty in enforcing this precaution; yet the only accident that occurred was caused by violation of this rule, a miner being slightly injured by the fall of a piece of rock he had neglected to pick down.

The foreman was always on the lookout for loose rock or places needing support. The superintendent never went into a tunnel without carefully examining the walls and roof, or into a deep surface excavation without examining the walls. It was repeatedly impressed on the miner that whenever the roof was not safe, his first duty was to pick down all loose rock and make it so, or if timbering was necessary, to get timbers and put them in place before undertaking any other work. As explained previously, on a claim where only one or two men worked the timbers were cut by the miner as needed, whereas on claims where a number of men were working a man was detailed periodically to cut timbers, which were then hauled by team to the miners' working place. As a further precaution against falls of roof the stopes were refilled with waste as soon as possible after excavation.

The handling of explosives was carefully supervised. The main supply of dynamite, rarely more than a ton at any one time, was kept in a dugout in a hillside. The dugout had a rock wall in front, a thick roof of timbers and earth, and was always kept locked, the mine foreman having the key. This magazine was dry, cool in summer and comparatively warm in winter, and sufficiently out of the way so that it was not visited except to obtain dynamite. As far as possible the dynamite was taken to the individual claims in the original unopened boxes, but where only a small quantity was required it was transported carefully in a canvas ore sack. The supply of fuse and caps were kept in a separate place under lock and key, and the small amounts for daily use at the claims were kept separate from the daily supply of dynamite. The miners were never permitted to handle dynamite carelessly. In cold weather hot-water powder thawers were supplied. Cap crimpers with wide crimping faces were furnished and their use was compulsory. In loading blast holes only wooden tamping sticks were permitted, a supply being kept on hand and issued as needed. As previously stated, the minimum length of fuse permitted was 2 feet, giving the miner about a minute and a half to seek shelter after igniting the fuse.

Before blasting, the warning cry of "fire" was always given several times and the fuse was not lighted until the rest of the miners in the vicinity had taken shelter. Misfires were rare, except in very cold weather, when the fuse, in spite of repeated warnings, was sometimes handled too roughly before it was thoroughly warmed. The miners had orders in case of a misfire to wait a safe interval of time before approaching the hole.

Intoxication, often a contributory cause of accidents in mining, was unknown, as the nearest saloon was at Placerville, Colo., 60 miles distant, and it was understood that any man discovered with liquor in his possession would be discharged immediately.

No sickness more serious than a slight cold occurred during the mining work, one contributing cause to this exemption being the supply of pure drinking water from local springs. During the first few months of the work the spring on the Maggie C mill site produced about two barrels of water a day, enough for domestic purposes, but in the dry season in 1915, the spring supplied just enough water for table use, and water for cooking and for the men to carry to their work had to be brought from a spring about a mile and a half distant. As the country above these springs was wild and uninhabited, the purity of the drinking water was assured. A simple, wholesome diet, as varied as possible, was supplied by the camp commissary. Empty cans and other refuse were carried some distance from the camp and buried. Chloride of lime was used freely as a disinfectant.

In addition to these precautions, literature on mine safety was liberally supplied to the miners.

PRODUCTION OF CARNOTITE ORE BY NATIONAL RADIUM INSTITUTE.

The table following gives data on all shipping-grade ore mined from the institute's leased claims prior to October 31, 1915, and represents 49 narrow-gage carload lots which were shipped to Denver, Colo. There were mined approximately 970 tons (gross weight) of ore, the net weight after sampling was approximately 960 tons, and the net dry weight, after deducting about 27¾ tons of moisture, was approximately 932 tons of ore averaging 2.6 per cent U_3O_8 content. In mining this shipping ore, about 2,000 tons of milling ore were produced having an average content of 0.8 per cent U_3O_8.

Formerly this low-grade ore was wasted in mining shipping ore, and as the recovery by concentration of the milling-grade ore was about 60 per cent, about 2,300 milligrams (theoretical content) of radium element were recovered by concentrating material which, in former years, was lost.

After the mining described in this paper, approximately 60 tons of shipping ore with an average content of 2½ per cent U_3O_8 were produced during assessment work for 1916, the total production of

shipping ore being, therefore, approximately 990 tons. Also, there was produced in 1916 from low-grade milling ore approximately 300 tons of carnotite concentrates with a U_3O_8 content averaging 3 per cent. The shipping ore contained approximately 51,000 pounds of uranium oxide and the concentrates about 18,000 pounds. Thus the total production of ore and concentrates represents approximately 69,000 pounds of uranium oxide, or its equivalent of about 8.8 grams of radium element.

Shipments of carnotite ore mined by the National Radium Institute from its leased claims up to October 31, 1915.

Car lot No.[a]	Number of bags.	Net weight after sampling.	Moisture.	Weight of water.	Net dry weight.	U_3O_8 content.	V_2O_5 content.	Weight of U_3O_8 in ore.	Weight of V_2O_5 in ore.
		Lbs.	*Per ct.*	*Lbs.*	*Lbs.*	*Per ct.*	*Per ct.*	*Lbs.*	*Lbs.*
1	900	64,767	2.25	1,457	63,310	2.26	5.43	1,430	3,437
2	1,100	79,075	2.08	1,644	77,430	2.71	4.45	2,098	3,445
3	1,063	73,688	2.00	1,473	72,215	2.81	4.06	2,029	2,931
4	1,096	79,160	2.40	1,900	77,260	2.83	3.87	2,186	2,989
5	1,109	78,884	2.00	1,577	77,307	2.44	3.46	1,886	2,674
6	1,091	78,145	3.00	2,344	75,801	2.21	4.43	1,675	3,357
7	1,099	80,865	6.60	5,337	75,528	2.32	4.40	1,752	3,323
8	1,042	70,545	5.20	3,668	66,877	2.76	3.77	1,845	2,521
9	1,199	82,625	5.40	4,462	78,163	2.31	4.40	1,805	3,439
10	1,154	78,925	3.60	2,841	76,084	2.24	3.83	1,704	2,914
11	1,103	76,635	4.20	3,218	73,417	2.56	4.21	1,879	3,090
12	1,238	82,625	2.70	2,230	80,395	2.53	5.04	2,033	4,051
13	1,186	82,645	3.00	2,479	80,166	2.85	3.64	2,284	2,918
14	1,092	73,510	4.09	3,007	70,503	2.37	4.16	1,670	2,932
15	1,205	83,880	1.90	1,593	82,286	2.97	3.97	2,443	3,266
16	1,171	79,065	2.63	2,079	76,986	2.98	4.44	2,294	3,418
17	1,158	78,130	1.33	1,039	77,091	2.53	3.64	1,950	2,806
18	1,244	82,810	1.41	1,167	81,643	2.61	4.02	2,130	3,282
19	1,168	79,935	2.55	2,038	77,897	2.89	5.07	2,251	3,949
20	1,177	81,705	2.67	2,181	79,524	2.51	4.13	1,996	3,284
21	1,102	78,945	2.52	1,989	76,956	2.69	5.15	2,070	3,963
22	1,090	74,475	3.00	2,234	72,241	2.63	5.55	1,899	4,009
23	1,102	79,999	1.99	1,592	78,407	2.37	4.78	1,858	3,747
24	1,056	75,425	1.49	1,124	74,301	2.85	4.46	2,117	3,313
25	586	43,081	2.30	991	42,090	2.52	4.59	1,060	1,931
Total	27,531	1,919,544		55,664	1,863,878			48,344	80,989
Average[b]			3.00			2.60	4.30		

[a] Lots 1 to 24 represent broad-gage railroad cars; lot 25 a narrow-gage car.
[b] Approximate.

CAUTION IN BUYING CARNOTITE ORES.

Caution is necessary in buying carnotite and other radioactive ores. Such ores have always been purchased on the basis of their uranium content, as determined by chemical analysis. This method ordinarily is sufficiently accurate as indicating the equivalent radium content of the ore. In general, and especially where ore is purchased from unknown sources, the method of determining the radium content of an ore from the chemical analysis for its uranium content is not satisfactory, especially if the ore is purchased with the prime object of extracting the radium.

Several instances are known to the writers where an admixture of yellow sodium uranate and other uranium compounds, which were

ground to the size of some of the grains of ore, was added. The radium from such material had been extracted, and as the sodium uranate and other uranium compounds usually have a high content of U_3O_8 it can be readily seen that a small quantity added to an ore is sufficient to increase the price of the ore considerably, and if such an ore is bought on the basis of its U_3O_8 content, and no special radium determination is made, serious losses will result to the purchaser. The admixture of small quantities of uranium compounds can not be easily detected by the unaided eye, but can be readily seen under the microscope when a careful examination of the material is made. Radium determinations should be made, therefore, on such ores by means of the electroscope.

Some carnotite ores contain considerable calcium sulphate and other sulphates which interfere with the extraction of uranium, vanadium, and radium by some processes. Such ores principally come from Utah, but are found in various parts of Colorado. Hence, carnotite ore should always be tested for its sulphate content.

Chapter II. GRINDING AND SAMPLING OF SHIPPING ORE BEFORE CHEMICAL TREATMENT.

During the early stages of the mining operations the National Radium Institute had its ore ground and sampled by other firms. As experience soon showed that this work could be done better and more cheaply in a special plant, the institute installed its own grinding and sampling plant at Denver, Colo.

The principal difficulty in crushing, grinding, and sampling carnotite ore is that much of the fine light dust produced can not be satisfactorily saved in plants constructed primarily for sampling ores that produce less dust, or heavier dust, than carnotite ore. This fine dust, being rich in carnotite, contains more uranium, radium, and vanadium than the coarser particles of the ground ore. Unless all of the machinery used in the crushing, grinding, and sampling is made practically dust proof and is provided with dust-collecting devices, much of this fine rich dust, some of which is as light as smoke, is lost, and a true sample of the ore is difficult to obtain. The problem of saving the dust, not only to prevent waste but also to obtain a true sample, had to be especially considered in constructing the sampling unit. The entire unit was made practically dust proof, and ample provision was made for collecting and sampling the dust.

DESCRIPTION OF CRUSHING, GRINDING, AND SAMPLING PLANT.

The hand-sorted shipping-grade ore as it came from the mines consisted of lumps that would pass through rings 1 to 3 inches in diameter, mixed with finer material. The coarse ore, previous to chemical treatment, has to be ground, and at first the ore, after having been crushed to ¼-inch size, was ground to pass a 40-mesh screen. As the capacity of the mill could be increased considerably by coarser grinding, tests were made to determine whether ore more coarsely ground could not be treated equally well. These tests proved that coarser grinding was an advantage, as it facilitated filtering. Thereafter all ore was reduced to pass through a 10-mesh screen placed at an angle of 45° and giving a product per screen test as follows:

Results of screen test of ground ore as delivered to the chemical plant; material passing 10-mesh screen placed at 45° angle.

	Per cent.
On 14 mesh	2.0
On 20 mesh	9.4
On 28 mesh	15.0
On 35 mesh	34.5
On 48 mesh	19.0
On 65 mesh	11.2
On 100 mesh	5.4
On 150 mesh	2.0
On 200 mesh	.6
Through 200 mesh	.9
	100.0

NOTE.—All dust collected passes through a 200-mesh screen.

As the ground material was easy to sample, the sampling device was inserted at that point. This device was so arranged that one four-hundredth of the entire weight of ore treated was cut and collected as a representative sample. (See p. 60.) This sample was mixed with an equal proportion of the dust collected, quartered, split and a final sample taken. The moisture sample was obtained in the usual manner just before the ground and sampled ore was weighed, as described on page 60.

DUST COLLECTION AND REMOVAL.

All connections between the individual apparatus were of strong galvanized-iron pipes and spouts, the joints being soldered. The elevator housing was of galvanized iron with all joints thoroughly packed. The screen and the sampling device were entirely inclosed. Access to the elevator and the sampling device could be had through close-fitting doors that were packed, hand screws being provided to hold them in place.

Tests made to determine what the loss would be without a fan and dust-collecting device showed that the loss of dust would be enormous; the dust from the crusher and the rolls made it almost impossible for anyone to remain in the grinding room, and the air currents created by the elevator and other moving parts carried the dust through all openings.

The dust from carnotite ore has a relatively high uranium content and is very irritating to the nose, throat, and lungs. Therefore health considerations alone necessitated the installment of fans and dust-collecting devices. The value of the escaping dust was considerable. For instance, the dust collected from a carload of 80,000 pounds of ore amounted to 1,500 pounds or about 2 per cent. In winter, when the ore arrives from the mines very moist, the amount would be less. This dust, however, averages about 8 per cent

uranium oxide, whereas the ore treated averages 2.5 per cent, so that the loss of carnotite in the escaping dust averages about 6 per cent. Of course, not all of the escaping dust was lost before the dust-collecting system was installed as some of it, after settling, could be collected from the floor and other places in the mill. The dust also works into the bearings and other wearing parts of the machinery.

Dust-collecting devices being an absolute necessity as regards safety, health, and economy, a Sturtevant "Monogram" No. 3 blower and a tubular dust collector were installed. The fan was run to give a capacity of about 1,250 cubic feet of air per minute. The dust collector consisted of two circular compartments each having 20 round openings 8 inches in diameter, to which cotton tubes or hose were attached. The lower compartment ended in a cone from which the collected dust could be drawn through a gate shutter. The 20 tubes, which were 16 feet long, practically filtered the dust from the air, the latter escaping through the meshes of the cloth. As some of the finest dust escaped through the meshes, the entire 20 tubes were surrounded by a sheet of cotton cloth, which was fastened to the outside wall of the upper and lower compartments. Thereafter practically all the dust was collected and saved. After the sampling of each carload of ore, the dust was drawn from the collector, and the entire unit thoroughly cleaned.

The fan, placed on the upper floor of the plant, was connected with the crushing and grinding apparatus by means of galvanized-iron pipes. Two 4-inch pipes were soldered into the upper side of the discharge spouts of the crusher and the rolls, respectively, and joined about 3 feet above the intake into one 7½ inch vertical pipe bent gradually to a right angle where it connected with the fan intake. This pipe was also connected with the intake spout of the elevator boot. The dust drawn into the fan was blown through a pipe into the upper compartment of the collector. Various other pipe connections provided, such as a dust intake pipe near the top of the elevator and one connecting with the screen housing were not necessary. Most of the dust from the crusher and the rolls was removed through the pipes connected to discharge spouts. Any dust which was not thus removed and was carried to the lower part of the elevator by the draft from the descending buckets was sucked into the spout connected with the fan.

OPERATION OF PLANT.

The plant was belt driven from a 25-kilowatt Westinghouse motor. One man operated the entire plant, dumped the ore into the ore bin, looked after the oiling and repairs, and sacked the ground ore. The final sampling was also done by him under the supervision and in

the presence of one of the Bureau of Mines employees. The capacity of the plant was approximately 10 tons per 8-hour shift.

The plan and sections of this mill are shown in Plates VII to X.

GENERAL PROCEDURE.

The ore was unloaded from the railroad cars, elevated to the upper floor of the grinding plant, and emptied into a bin holding about 25 tons. Through an opening 1 foot square in the ore bin *1*, the ore was mechanically fed through a swing-gate feeder, *2*, over a chute into a 5 by 9 inch Sampson crusher, *3*, set to crush the ore to ¼-inch size. The crushed ore dropped through a spout, *4*, into the boot of a bucket elevator, *5*, and was then elevated to the upper floor in the building, where it was discharged into the feeder, *6*, of a Newago 10-mesh vibrating screen, *7*, set at an angle of 45°. The oversize from the screen fell into a feed pipe, *8*, and dropped into the hopper of a set of 12 by 12 inch Davis rolls, *9*, on the lower floor of the building. The rolls were set close enough to make a product passing the Newago screen, and this product dropped through a spout, *10*, into the elevator boot, *5*. The material elevated to the upper floor of the building discharged into the feeder, *6*, of the vibrating screen, *7*. The oversize was returned by gravity through spout *8* to the rolls, *9*.[a] The undersize from the screen was fed by gravity through spout *11* into the sampling device, *12*, which was suspended from the upper floor of the building. The reject from the sampling device dropped through a spout into the ore bin, *14*; the sample, representing about one four-hundredth of the quantity of ore treated, was collected in a small sample bin, *18*. Both the ore bin for collecting the reject, and the sample bin are made of heavy galvanized iron and are dustproof. A flow-sheet of the process follows:

[a] Only one elevator was installed for handling the products from the crusher and the rolls.

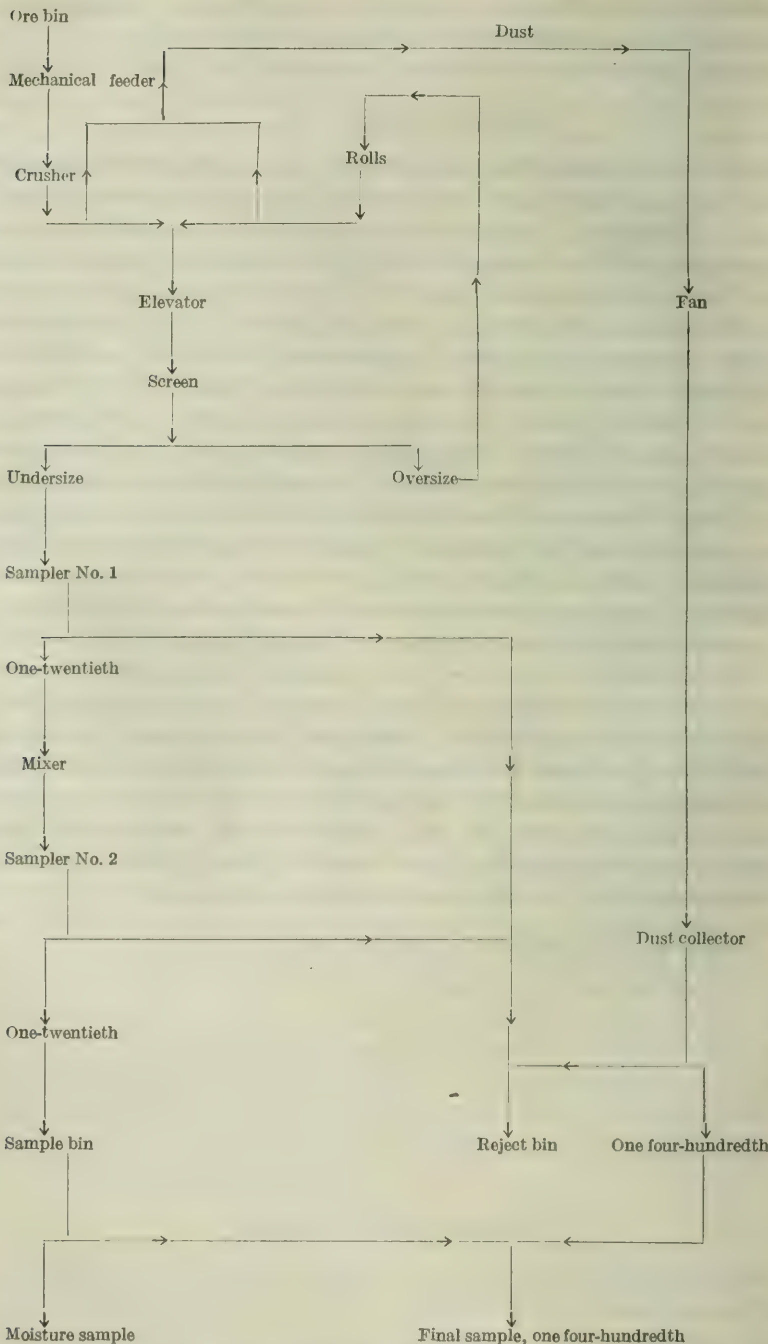
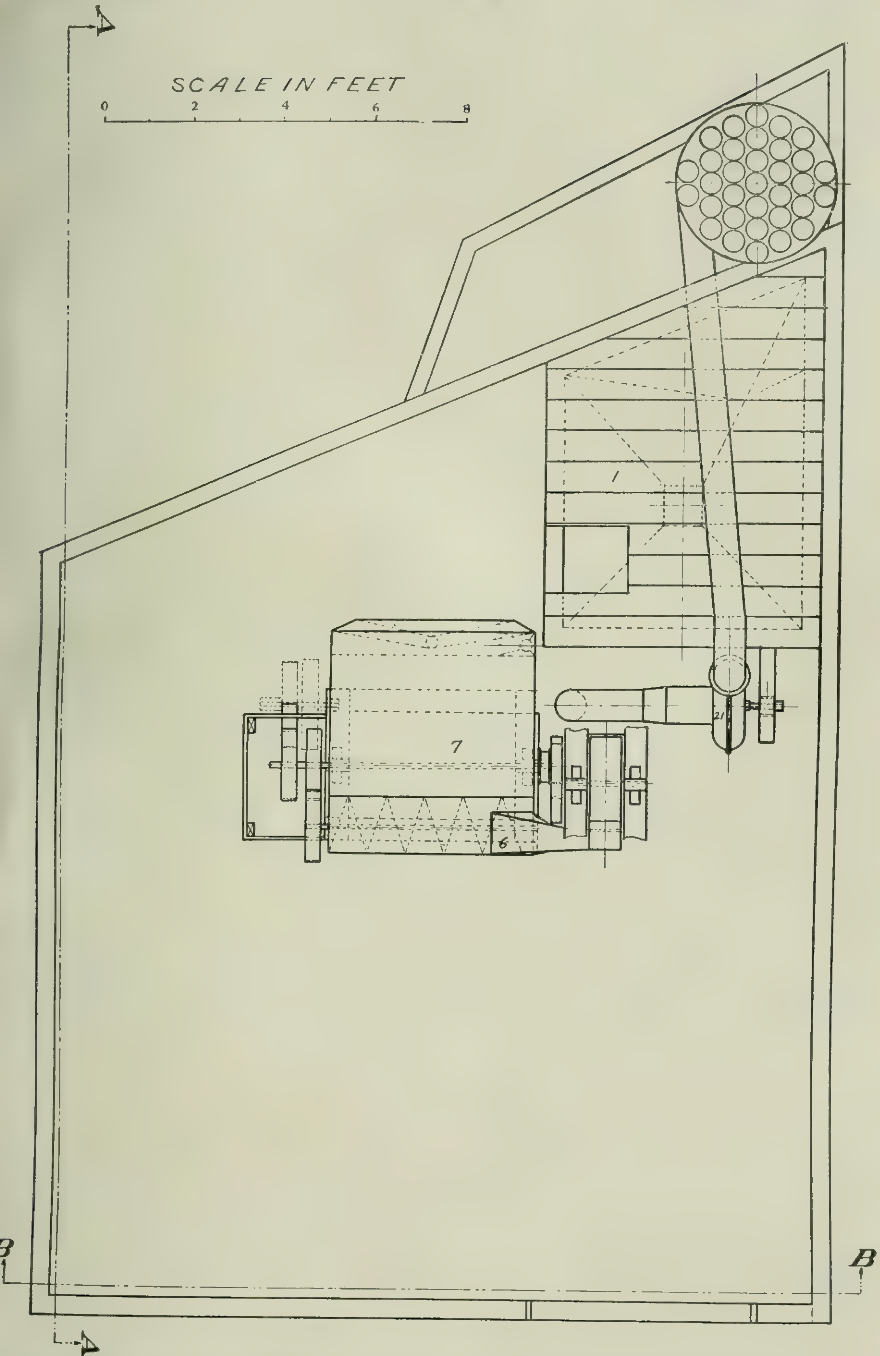
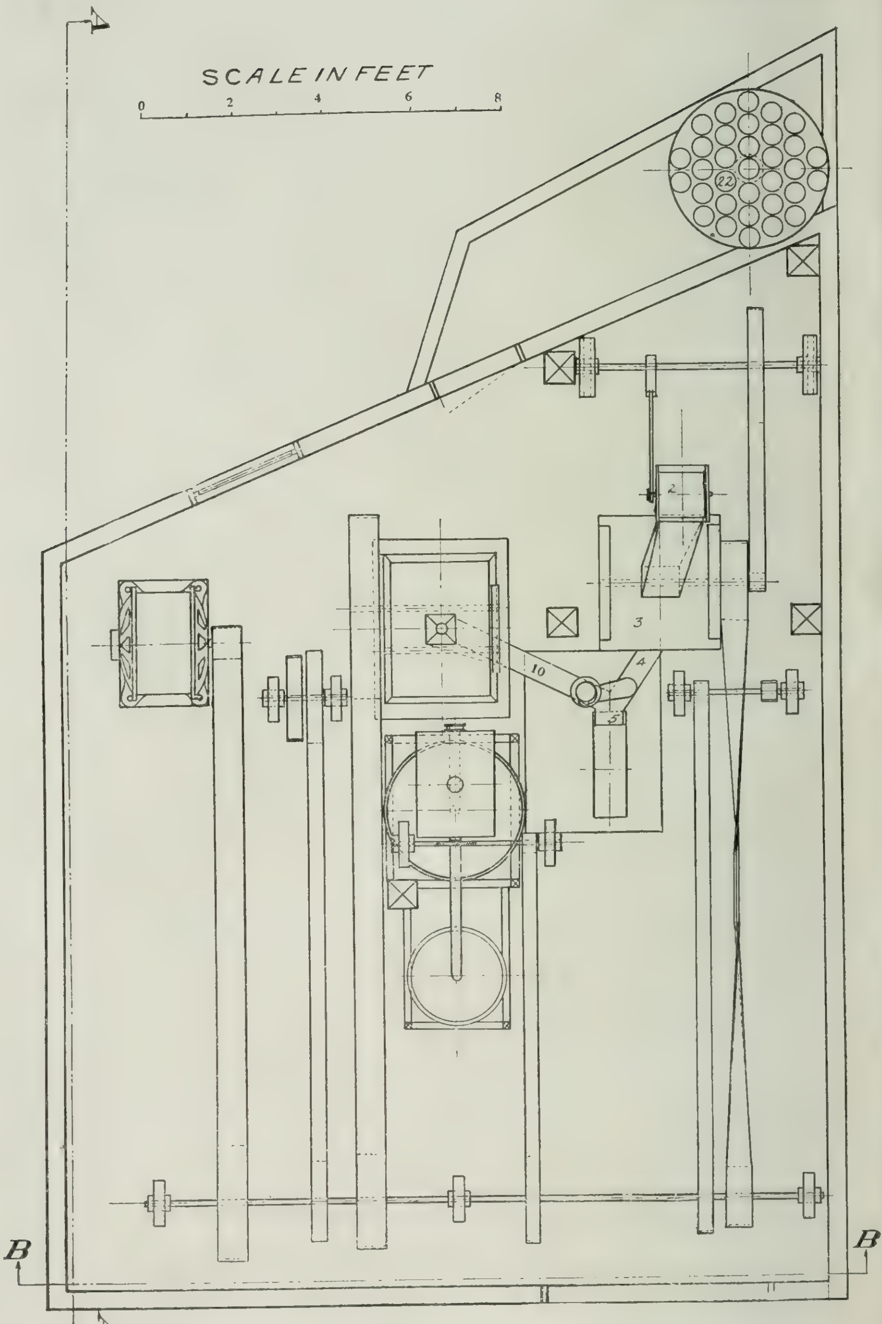


FIGURE 3.—Flow sheet of process of crushing, pulverizing, and sampling carnotite.



SECOND-FLOOR PLAN OF GRINDING AND SAMPLING PLANT OF NATIONAL RADIUM INSTITUTE AT DENVER, COLO.



FIRST-FLOOR PLAN OF GRINDING AND SAMPLING PLANT AT DENVER, COLO.

MECHANICAL SAMPLING DEVICE.

The mechanical sampling apparatus consisted of two Snyder samplers with a mixer between. These samplers were cast-iron pans 16 inches in diameter with flaring sides, set edgewise on a horizontal revolving shaft. A spout projecting through the flaring side of the pan passed under the feed spout at each revolution of the machine and cut and delivered a sample.

As shown in figure 4, the operation was as follows: Spout *b*, projecting through the flaring side of pan *a*, passed at each revolution under feed spout *c* and delivered a sample into the spout *d* of the

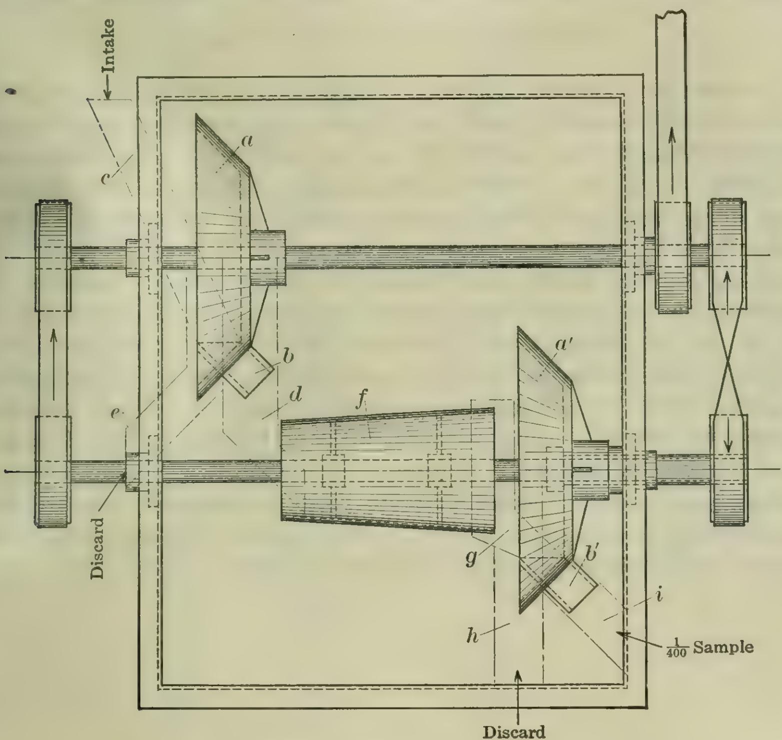


FIGURE 4.—Sampling device.

revolving mixer *f*. During the remainder of the revolution of the pan *a* the stream of ore from feed pipe *c* was diverted as reject into spout *e*. The cut sample from the first pan passed through spout *d* into the mixer *f*, and the mixed material was discharged therefrom into feed spout *g*. The stream of the sample passing from spout *g* was again cut by the projecting spout *b′* of the second pan *a′* at each revolution, the cut sample passing into spout *i*, which was connected with the sample bin below. The stream of ore during the remaining part of each revolution was diverted by the flaring side of pan *a′*, and was

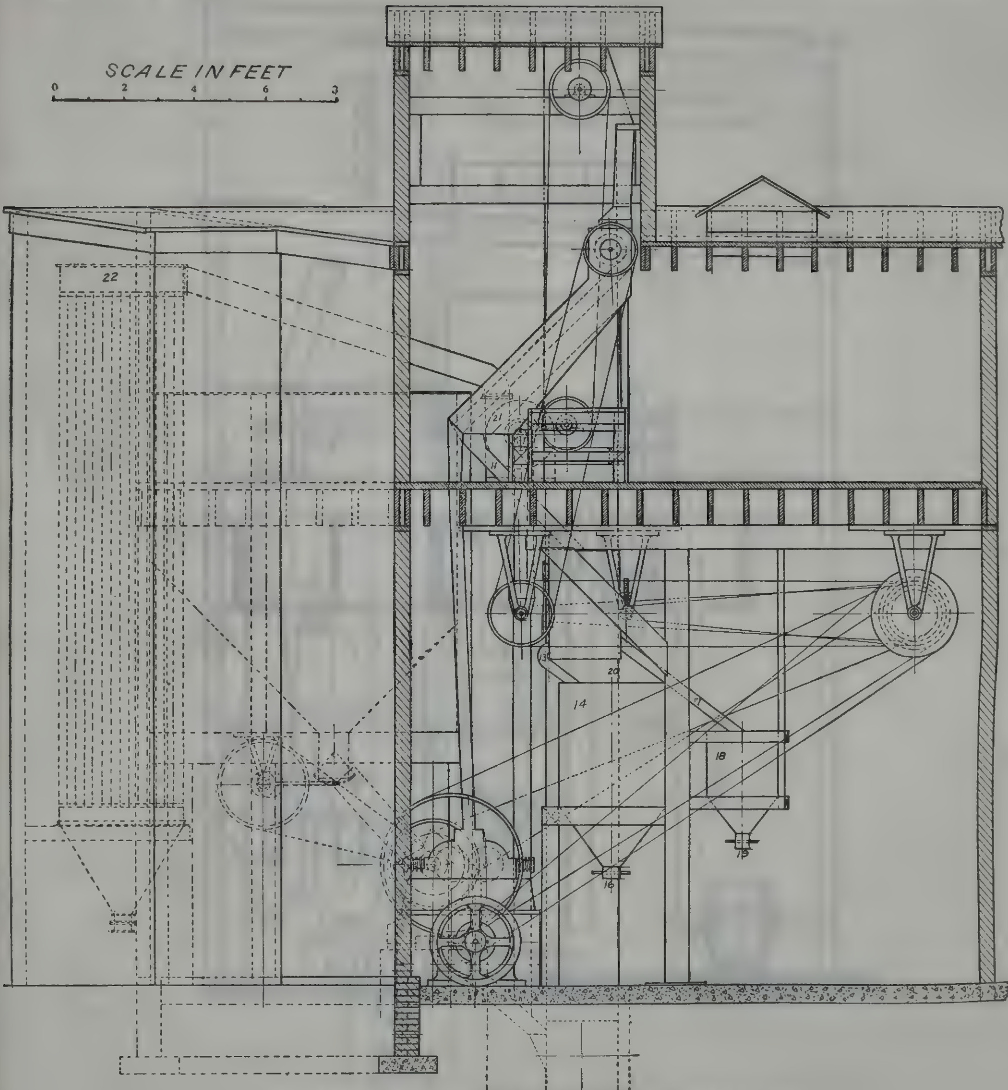
delivered as reject through pipe *h* into the ore bin below. Pipes *e* and *h* were connected with the same ore bin.

The entire sampling machine was inclosed in a dust-proof box made of galvanized iron 28 by 20 inches, by 45 inches high. One side of the housing could be removed for inspection of the machine; the other contained a door. The removable side was packed with felt, and the door was fastened to the box by means of hand screws.

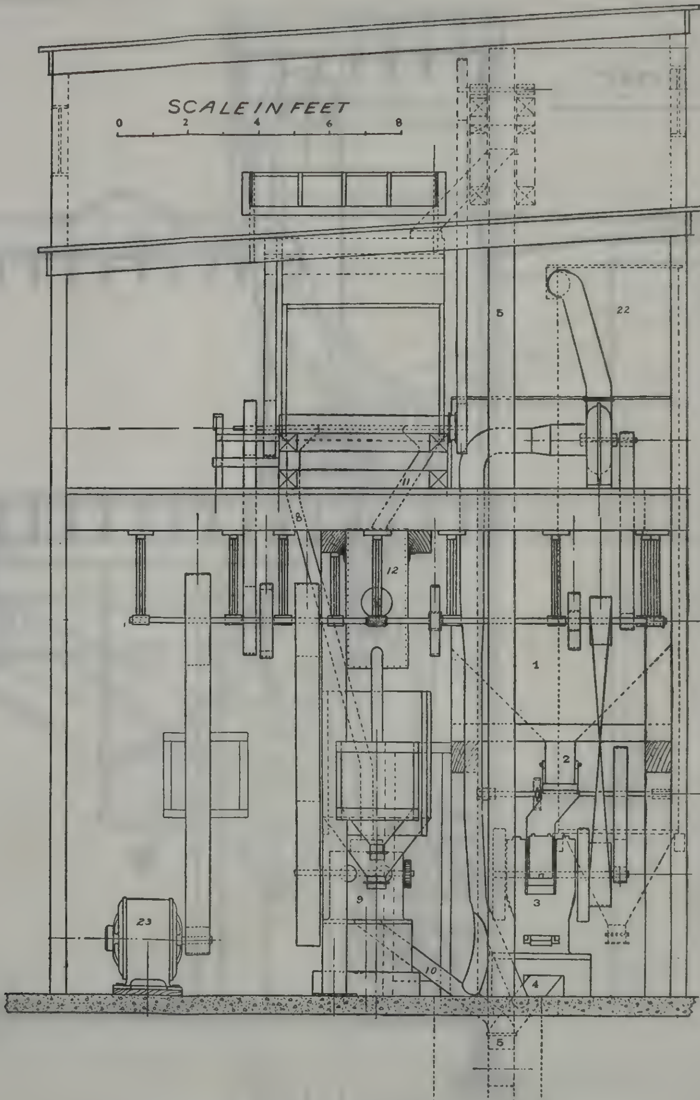
The opening of the spout in the pan was $1\frac{3}{4}$ inches. One-twentieth of the entire quantity treated was cut by the first pan, the second pan also cut one-twentieth of the sample, the final sample obtained being one four-hundredth of the total ore passed through the machine.

COLLECTION OF MOISTURE SAMPLES.

As soon as an entire carload of shipping ore had been ground and mechanically sampled, and just before the ore was weighed, the moisture sample was taken from the ore collected in the sample bin. As both the rejected ore from the sampler and the cut sample were kept in air-tight galvanized-iron bins under like conditions, the moisture sample was taken from the mixed sample (see p. 55) before the final cutting was made. In the early stages of plant operation the moisture samples were taken before the ore was dumped into the ore bin of the sampling plant. By careful tests the authors found that the moisture content of the ore varied slightly during the sampling, the ore, which is extremely hygroscopic, losing or gaining moisture during the process. As the ore was weighed after sampling, it seemed best to take the moisture sample at the same time. The moisture sample was quartered down and the final cut was put at once into hermetically sealed glass bottles. The moisture content was determined in the laboratory of the Bureau of Mines.



SECTION *A-A* (PL. VIII) OF GRINDING AND SAMPLING PLANT AT DENVER, COLO.



SECTION *B-B* (PL. VIII) OF GRINDING AND SAMPLING PLANT AT DENVER, COLO.

Chapter III. CONCENTRATION OF MILLING ORE.

In mining carnotite ore of shipping grade considerable low-grade ore is produced which is not rich enough in uranium content to warrant shipment, but may contain as much as 1¼ per cent of uranium oxide, the average at the claims of the National Radium Institute being, according to observations of the authors, about 0.8 per cent. At many mines such ore formerly was not kept separate from the waste rock but was sent to the dump. The ratio between the amount of milling ore and the amount of shipping ore produced in mining varies greatly, as low as one-quarter ton of milling ore per ton of shipping ore being produced in places where the pockets were exceptionally rich, but in mining poor ore as much as 10 tons of milling ore per ton of shipping ore have been mined.

Early experiments showed, as stated in a previous publication,[a] that it was possible to concentrate the carnotite from these low-grade ores by either the wet or the dry method and thus prevent the relatively large waste of radium which the mining of carnotite had entailed. In most districts of the carnotite belt dry concentration is perhaps preferable, as water is scarce. Concentrating the low-grade ores reduces the bulk and increases the uranium content, thus effecting a considerable saving in haulage and freight and making shipment profitable. Where enough water is available wet concentration can be applied. As all the claims operated by the National Radium Institute were in an arid region, where no water for concentration was available, the dry method was chosen.

To investigate this problem and, if possible, to put the concentration of carnotite on a commercial basis, an experimental mill was erected by the National Radium Institute on the Maggie C claim, and extensive tests were conducted with low-grade ore. All milling ore mined on the various claims was carefully separated and placed in as available localities as possible. The ore on the Maggie C claim was used for the early experimental tests, about 50 tons of concentrates being produced, which contained 3 to 7 per cent uranium oxide. As these tests were a success the mill was enlarged and improved. Its equipment and the results obtained are described in a later chapter. Views of this mill are shown in Plates V, *B* (p. 40) and VI, *B* (p. 48).

[a] Moore, R. B., and Kithil, K. L., A preliminary report on uranium, radium, and vanadium: Bull. 70, Bureau of Mines, 1914, pp. 35–40, 111–112.

METHODS OF CONCENTRATING CARNOTITE.

As carnotite partly forms the binder between the sand grains of the sandstone, it must be separated from these grains in order to concentrate it. Consequently the ore should be reduced to about the fineness of the sand grains. Care must be taken that as little as possible of the silica is ground to powder, as the concentration depends largely on the removal of fines or slimes from the coarser material. Some of the carnotite adheres tenaciously to the surface of the sand grains and can be liberated only by attrition or elutriation. In the especially devised attrition apparatus, described later, the ground ore is rubbed by means of rotating brushes pressing against the surface of a circular plate.

In order to concentrate the fines or slimes, which contain most of the carnotite, either the wet or dry method of concentration can be used. In the wet method advantage is taken of the difference in rate of settling of different sizes of the agitated material, followed by decantation and final settling of the slimes, which form the concentrate. Dry concentration suggests the use of air to blow or suck the fines from the coarser particles.

A complete description of the dry methods used in the concentration mill of the National Radium Institute are given in the following pages. A description of wet methods of treatment is also included as being of general interest, although not used in this work.

ATTRITION OF THE GROUND ORE BEFORE CONCENTRATION.

It was found that after the ore had been ground to about 80 mesh or finer all of the carnotite could not be entirely liberated by ordinary means. In order to save this carnotite a special attrition apparatus was constructed whereby the adhering carnotite was rubbed or scraped from the silica grains mechanically by passing the ground ore between a pair of disks, on one of which was a number of stiff wire brushes. The disks were placed one above the other in a horizontal position, the brushes being attached in spiral form to the lower side of the upper disk. The lower disk was rotated by mechanical means. The material to be treated was fed through a hopper near the center of the rotating lower disk and was carried gradually toward the outer edge, the constant attrition by the wire bristles removing much of the adhering carnotite from the silica grains. The entire apparatus was made practically dust proof to save the liberated dust, which contained the valuable carnotite. The air current caused by the rotation of the disk tended to whirl up the liberated dust, which was removed through a hole in the upper side of the housing by a vacuum cleaner, and formed the concentrate.

The disks were 3 feet in diameter, and approximately 2 tons of material could be treated during 8 hours.

This capacity was insufficient for milling on a commercial scale, and the Raymond pulverizing and dust-collecting system was finally adopted. The manufacturers of that system had already made somewhat similar experiments with finely ground ore for other parties. This dry concentration, with previous coarse grinding, was ultimately chosen by the National Radium Institute for its ore and is described in detail later.

WET CONCENTRATION OF CARNOTITE ORES.

In the application of the wet method, the ore should be carefully ground to about 80 or 100 mesh. Before separation it will be necessary to elutriate the ground material in order to liberate the more tenaciously adhering carnotite from the silica grains. The elutriated material should then be agitated in tanks with ample water. After agitation the coarser particles are allowed to settle and the liquor, with the pulverulent carnotite and other fine material (slimes) which remain in suspension, is decanted into settling tanks. Water is added to the residue, and the operation repeated, as some of the carnotite is carried down by mechanical action with the coarser silica grains. A number of settling tanks should be employed, as it takes some time for all the slime to settle. After thorough settling of the slime the water can be drawn off and, if necessary, can be used again. The settled slimes form the concentrate.

Fischer [a] suggests that the crushed and ground ore be brought into a Dorr classifier, which mechanically separates the coarse material from the slimes, and thereby accomplishes concentration at the same time. The concentrates are carried by a launder into a Dorr thickener, where most of the water is eliminated. The moist material is then dried. The dried cake can be broken and put into bags. Fischer claims that a concentration of 3:1 can be effected in this way, the concentrates being three times as rich as the original low-grade ore. Therefore an ore containing 0.75 per cent U_3O_8, according to Fischer's figures, would give a concentrate containing only about 2.25 per cent U_3O_8. Such a product seems very low grade, and no doubt better results than these can be obtained by wet concentration.

J. V. N. Dorr suggested to the authors that in addition to the classifier and slime thickener, a number of settling tanks similar to those used in countercurrent decantation be provided in order to make the process more continuous. Such a method will require the use of elutriation in order to make a better recovery. The carnotite

[a] Fischer, Siegfried, The carnotite industry: Trans. Am. Electrochem. Soc., vol. 24, 1913, pp. 365-368.

adhering to the sand grains must first be liberated and agitation with water alone will not free it, as many tests have shown.

Although the Dorr classifier apparently ought to give good results in the wet concentration of carnotite ores, other systems of agitation followed by decantation and settling should also be of commercial use wherever enough water is available.

Nothing is known as to the cost of such methods, but it should be low.

PROCESS USED BY NATIONAL RADIUM INSTITUTE.

In concentrating low-grade ore the National Radium Institute, as previously stated, employed the dry method because the water supply at Long Park was sufficient for domestic use only.

DESCRIPTION OF PLANT DURING EXPERIMENTAL STAGE.

The concentration mill, built on the Maggie C claim, was equipped during the experimental stage with an ore bin, a 5 by 9 inch Sampson crusher, and a Raymond No. 00 pulverizing machine with a tubular dust collector. The crushed ore was dried before it was pulverized. During the experimental work, the drier was a steel plate one-fourth inch thick, 6 feet long and 3 feet wide, with edges turned up on three sides, which was placed on a low stone firebox, in which a coal or wood fire was built. The machines were driven by a 25-horsepower Fairbanks-Morse kerosene engine.

The Raymond machine had a beater chamber containing two sets of rapidly revolving beaters. Over the beater chamber was a cone of galvanized iron, within which was an inner cone provided at its lower end with a swinging discharge gate. The two cones were connected at their upper ends by a number of small gate shutters and had a common top or cover plate. A large pipe from the center of their top led to an exhaust fan mounted on the same shaft as the beaters. This fan discharged into a cyclone dust and air separator, which was connected by a return pipe with the beater chamber of the pulverizer. A small pipe led from this return pipe to a tubular dust collector. Both the cyclone separator and the tubular dust collector had discharge gates at their lower end.

The Raymond mill is used extensively to pulverize cement, paints, etc. In such work the beaters reduce the material to a fine powder. In the concentration of carnotite, however, such pulverizing proved unnecessary and even detrimental, the function of the beaters being chiefly to stir up the ground ore fed into the machine so that the carnotite dust could be removed from the larger grains of silica. With this machine the use of any other attrition was unnecessary, as the silica grains whirled around in the beater chamber rubbed against each other

and the lining of the chamber. The beaters also caused further disintegration of the material into grains, thus liberating the adhering carnotite.

The finer material was drawn by suction into the space between the outer and inner cones, but the coarse particles dropped out of the air current and fell back into the beater chamber. Here the stronger air current practically air washed the coarser particles free from the dust, after which they automatically dropped through the tailing spout at the front of the pulverizer. The finer material passed through the gate shutters into the inner cone, where a further separation took place, the finer particles being drawn through the fan, while the coarser particles fell to the bottom of the inner cone and were automatically discharged again into the beater chamber.

The volume of air used was large, and the air current was light enough to carry off the fine powder. The fan blew the dust into the cyclone separator, where the dust was separated from the air and automatically discharged as concentrate No. 1. This cyclone air separator furnished the bulk of the carnotite concentrate. The surplus air was returned through a connecting pipe from the top of the separator into the pulverizer; a certain amount of this surplus air blown into the tubular dust collector through a smaller pipe, furnished concentrate No. 2, which consisted of the very finest dust, and hence was richer than concentrate No. 1. However, the amount collected was comparatively small, only about $1\frac{1}{2}$ per cent of the weight of concentrate No. 1.

The ore was dumped onto the drying plate in about 250-pound lots and stirred by hand with an iron rake until dry, much dust being carried away mechanically with the steam. This drier had a capacity of $4\frac{1}{2}$ tons of ore a day with three shifts. The dried ore was fed by hand into the feed hopper of the pulverizer. During these experiments about 50 tons of concentrate No. 1, containing about 3.25 per cent uranium oxide, and 1,600 pounds of concentrate No. 2, with a uranium oxide content of about 6 per cent, were produced. The ratio of concentration was about 6:1. The recovery of U_3O_8 in the concentrate during the experimental stage was about 50 per cent.

The experimental mill required the following help: One foreman, one crusher man, one laborer to carry ore to the drier, three drier men (one for each of three shifts per day), and one man to feed the pulverizer and remove the tailings.

Coal and wood were used for the drier. The coal was hauled from a mine near Nucla, Colo., a distance of about 20 miles. The wood was local pinon and scrub cedar. The kerosene for the engine had to be hauled from Placerville, Colo., a distance of about 58 miles.

DESCRIPTION OF COMPLETED CONCENTRATION MILL.

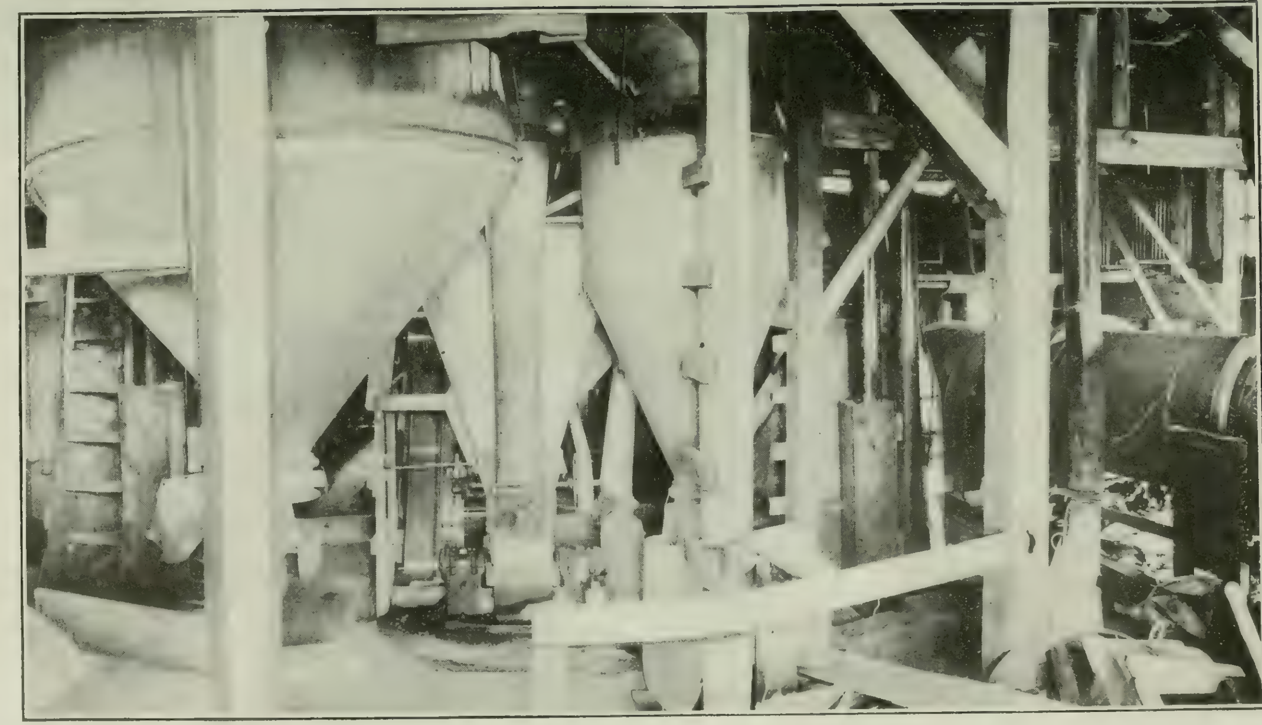
As the experimental results were satisfactory, the National Radium Institute decided to complete the mill and operate it on a commercial basis. In addition to the apparatus already described, the following equipment was installed: A mechanical drier and fan, a cyclone dust collector, 2 sets of rolls, 2 bucket elevators, an ore-belt conveyor, a tailings belt conveyor, a vibrating screen, additional fans, piping and dust collectors, and another 25-horsepower Fairbanks-Morse kerosene engine. Plate XI shows the interior of the mill.

The new equipment necessitated changes and additions to the mill building. The completed building was 38 feet 6 inches long and 30 feet wide, the greatest height was 23 feet; the engine room was 13 feet high on one side, sloping to 11 feet. On the north side, a small shed 10 by 10 by 10 feet, formerly used as the drying room, served as a storage room. All new additions had a light framework covered with painted corrugated iron.

Plates XII, XIII, and XIV show the plan view, section A–A, and section B–B, respectively. In the illustrations *1* designates an ore bin built on a foundation of piled rock . The bin was made of heavy timber and planks, fastened together with iron rods threaded at either end. It was 8 by 10 by 10 feet in size, and held about 40 tons of milling ore. At its lower end the bin had an opening about 8 inches square, beneath which was a swing-gate feeder *2* that discharged into a chute, *3*, placed at an angle of 45°. The upper part of the bottom side of this chute held a strong wire screen with ½-inch apertures. The chute ended in a spout that discharged through a pipe into the boot *5* of elevator No. 1. The screen of the chute extended to the feed hooper of a 5 by 9 inch Sampson crusher, *4*. The discharge spout of the crusher connected with elevator boot *5*.

This elevator had 3½ by 5 inch steel buckets mounted on a 6-inch rubber belt, and was housed in 8-inch pipes. Belt conveyor *6* had a 10-inch rubber belt supported on wooden rollers. The two pulleys were mounted on a framework of 4 by 4 inch lumber. Underneath the conveyor frame was a semicircular pan to keep pieces of rock from falling into the mill below.

At the discharge end of this conveyor a small hopper and pipe, *7*, connected with the feed hopper *8* of a Ruggles-Cole single-shell rotary drier, *9*, with a shell 12 feet long and 3 feet in diameter. The smokestack, *22*, at the upper end of the drier had in one side an opening connected by a pipe with a Buffalo No. 5 blower, *23*. Both the smokestack and the pipe had dampers. The smokestack was used when the fire in the drier was started. The blower, which was used exclusively during operation, was connected through another pipe with a cyclone dust collector *24* on the roof of the building.



INTERIOR VIEW OF CONCENTRATING MILL AT LONG PARK, COLO.

The outlet at the top of the cyclone was 28 inches in diameter, and was connected through a 28-inch pipe with an especially constructed dust collector, or bag house *24a*, consisting of a cylindrical upper compartment or tank made of No. 16 galvanized iron, and a lower compartment which was cone shaped. These were 7 feet 6 inches in diameter, and were connected by an inner hose made of burlap, which was surrounded by another hose made of unbleached muslin, the length of each hose being 10 feet. The upper compartment had a circular opening at the top 3 feet in diameter, over which was stretched a piece of burlap. The gases escaped partly through the hose and partly through the burlap; the dust was collected inside and was drawn off at the opening in the lower end of the cone.

Trial runs had shown that much dust escaped from various points in the apparatus. In order to save this dust, a system of 3-inch galvanized iron pipes was attached at the points where the chutes from the crusher and screen and those from the drier and rolls entered the upper side of the boots of elevators Nos. 1 and 2, respectively. These pipes, which were almost vertical, connected with a 7½-inch pipe leading to the intake of a Buffalo No. 3 blower fan. Another pipe 7½ inches in diameter was connected with the outlet of this blower, and at its lower end was fitted into the top of dust collector *24*. The blower had a dust trap in its intake and another trap in its outlet. At the lower end of the drier and near the fire box *9a* a discharge spout, *10*, led into the boot, *11*, of the elevator No. 2. This elevator had 3½ by 5 inch steel buckets fastened to a sprocket chain and was housed completely, 8-inch pipes being used between the boot and the head. Its discharge spout was soldered to the feed hopper of a vibrating screen, *12*. A small screw conveyor in the upper part of the screen housing fed the ore to a ¼-inch screen, 4 inches below which was a 10-mesh screen. Both screens were placed at an angle of 45°. The entire screen housing was made practically dust proof, and two spouts at the lower end ended in 4-inch pipes of No. 16 galvanized iron which connected with the feed hopper of a set of 9 by 12 inch McFarland rolls, *13*, and a set of 12 by 12 inch Sturtevant rolls. The latter are not shown in the plates, as they were installed later. The oversize of the ¼-inch screen went to the McFarland rolls and the oversize of the 10-inch screen to the Sturtevant rolls for further grinding. The material passing through the 10-mesh screen went to the storage hopper, *14*, of the pulverizer. Discharge spouts from the rolls led into the boot, *11*, of elevator No. 2. Nos. *15* to *19* designate the Raymond mill and the dust-collecting system described. Below the tailings spout of the pulverizer, *16*, was installed a horizontal tailing belt conveyor, *25*, 8 feet long, which discharged at right angles on a tailing belt conveyor *25a*, 35 feet long, with a 17 per cent upgrade, which extended

through the east side of the building, the outer end being supported on a scaffold about 25 feet from the building. This conveyor was of rubber belting 10 inches wide supported by rollers, with a 12-inch iron pulley at each end.

Four water tanks, *27*, outside the building furnished the cooling water for the two 25-horsepower engines, *26*. Kerosene feed tanks, *28*, were buried in the ground near the water tanks. Power was transmitted by two shafts; one making 530 revolutions per minute drove the Raymond machine and the tailings conveyors. The other shaft, making 200 revolutions per minute, drove the rest of the machinery. Thus the mill could have been operated in two

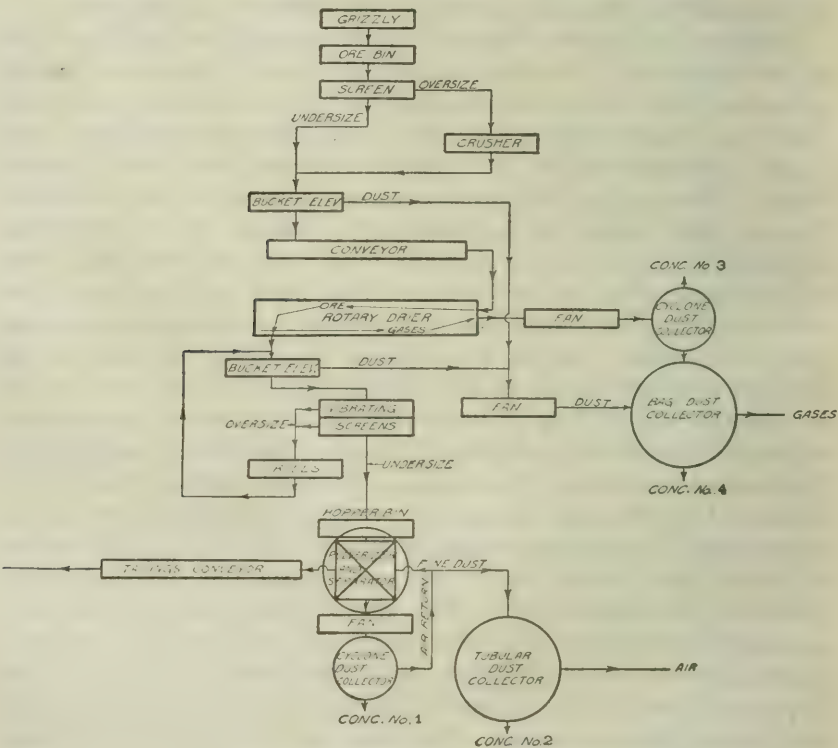


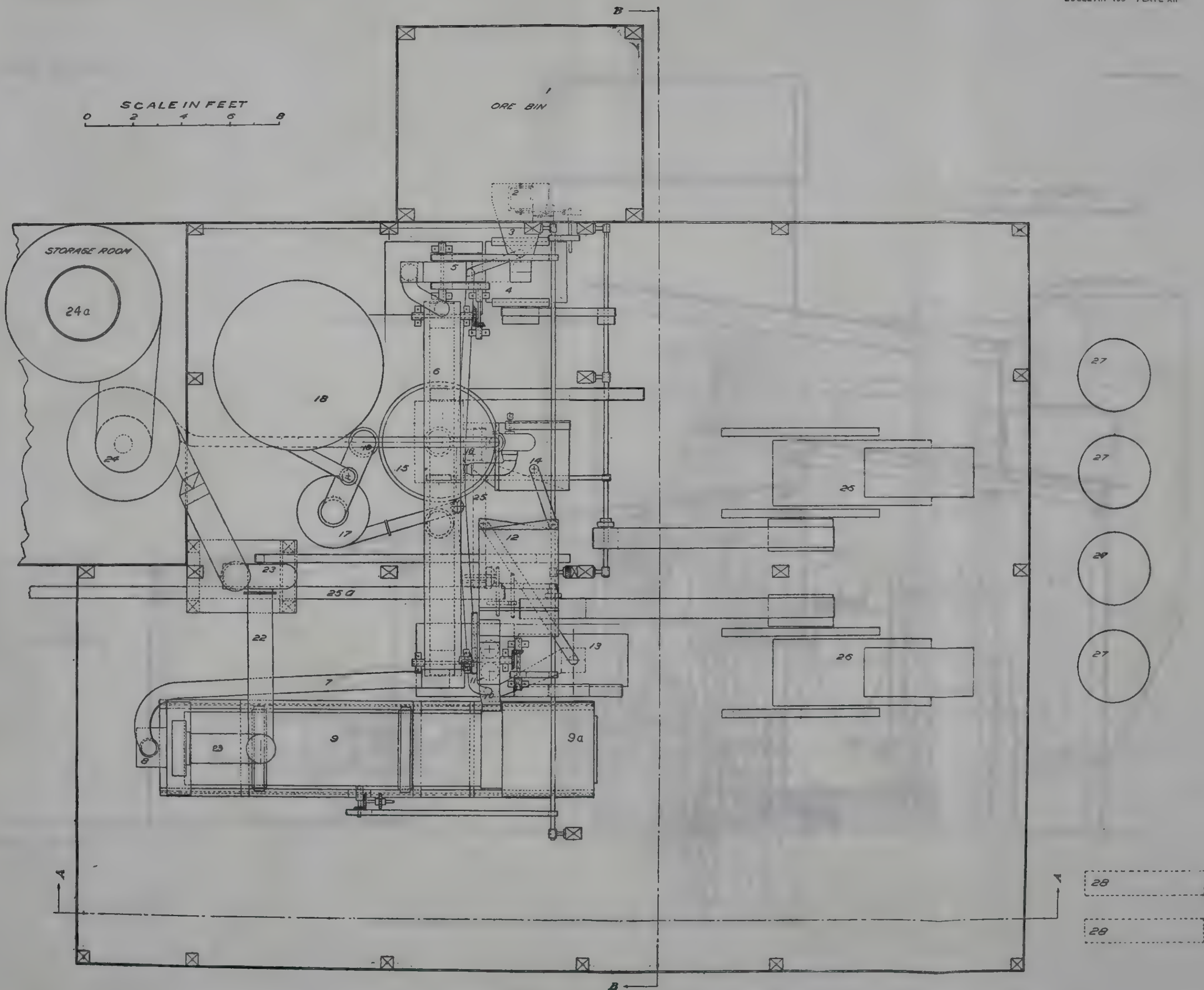
FIGURE 5.—Flow sheet of concentrating mill.

units if necessary on account of a breakdown of either unit. Ample provision was made for storage of the ground ore in the pulverizer hopper, *14*.

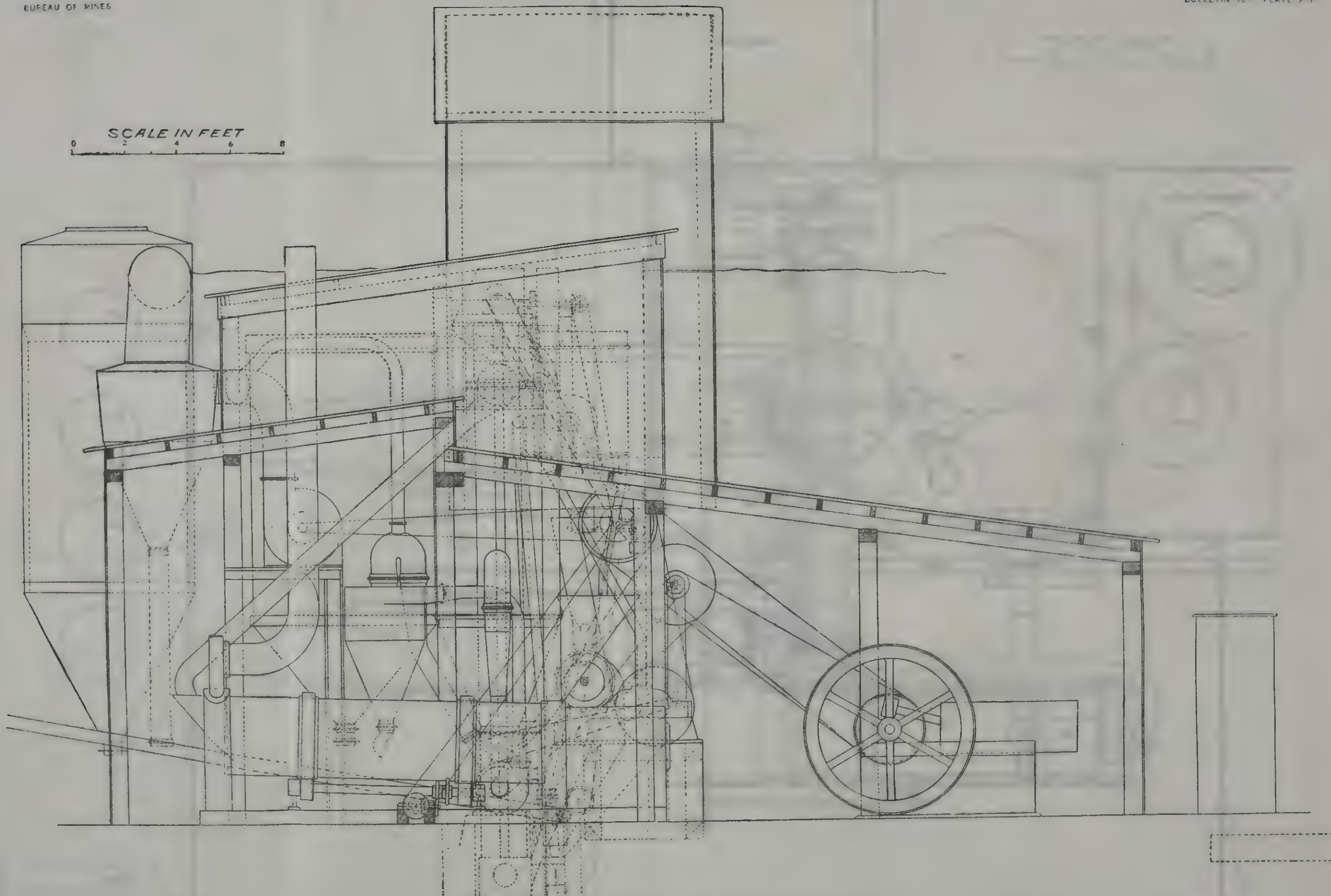
A coal storage bin was built at the east side of the building, and a smaller one inside for daily use.

COURSE OF ORE IN THE MILL.

The course of the ore through the mill is indicated by the flow sheet shown in figure 5. The milling ore was dumped onto the grizzly (Pl. V, *G*, p. 40), which had bars spaced 1¼ inches apart; the larger pieces



PLAN OF CONCENTRATING MILL AT LONG PARK, COLO.



SECTION *A-A* (PL. XII) OF CONCENTRATING MILL AT LONG PARK, COLO.

of rock were broken with a rock hammer. Pieces of waste rock were thrown out. From the ore bin the ore was fed mechanically onto a ½-inch screen placed at an angle of 45°. The oversize dropped into the crusher, the jaws of which were set to make a ¼-inch product. The undersize dropped through a chute into the boot of elevator No. 1, as did the material passing through the crusher. The material discharged from the elevator was carried by belt conveyor No. 1 across the building and dropped through a pipe into the feed hopper of the rotary drier. In passing through the drier the ore was repeatedly lifted by the shelves within and poured through the hot gases coming from the fire box at the lower end. Considerable dust was liberated, which was carried with the gases and steam into the smokestack. To save this dust all gases and steam were drawn off by the fan through the pipe connected with the smokestack and blown into the cyclone dust collector. Through a pipe at the lower end of this collector the separated dust was drawn off. This dust formed concentrate No. 3.

Considerable very fine dust carrying carnotite escaped through the opening at the top of the cyclone separator and was blown through another pipe into the dust collector, or bag house. The dust so collected formed concentrate No. 4. The dried ore left the drier at its lower end near the fire box and discharged into the boot of elevator No. 2. The hot ore was elevated to the vibrating screen, where the screw conveyor distributed it equally over the screening surface. The oversize of both the ¼-inch and 10-mesh screens fell through pipes into the feed hoppers of the two sets of rolls; the undersize passed through a chute to the storage hopper of the Raymond mill. The screened material consisted of ground ore as shown by the following screen test:

Results of screen test of ground ore as fed to Raymond mill.

	Per cent.
On 35 mesh	13.8
On 48 mesh	18.0
On 65 mesh	27.4
On 100 mesh	19.6
On 150 mesh	13.2
On 200 mesh	2.7
Through 200 mesh	5.3
	100.0

The oversize, after passing the rolls, dropped again into the boot of elevator No. 2, and was returned to the screen until all of it passed through the 10-mesh screen. The ground and dried ore from the storage hopper was automatically fed into the pulverizer chamber of the Raymond mill, when the carnotite was separated from the silica grains, as already described. The tailings, which automatically dis-

charged from the pulverizer, dropped onto the tailing conveyor and were carried to the dump. The size of the tailings corresponds to the following screen test:

Results of screen test of tailings.

	Per cent.
On 35 mesh	3.0
On 48 mesh	8.0
On 65 mesh	20.4
On 150 mesh	57.0
On 200 mesh	11.6

The tailings were practically free from carnotite dust.

The blower fan connected with the boots of elevators No. 1 and No. 2 drew off the dust from these points and blew it into the dust collector already described.

It is essential in concentrating carnotite ore by the dry method that all apparatus be so inclosed and connected with each other as to make the entire unit dust proof, for all dust created in the mill contains carnotite and is part of the concentrate.

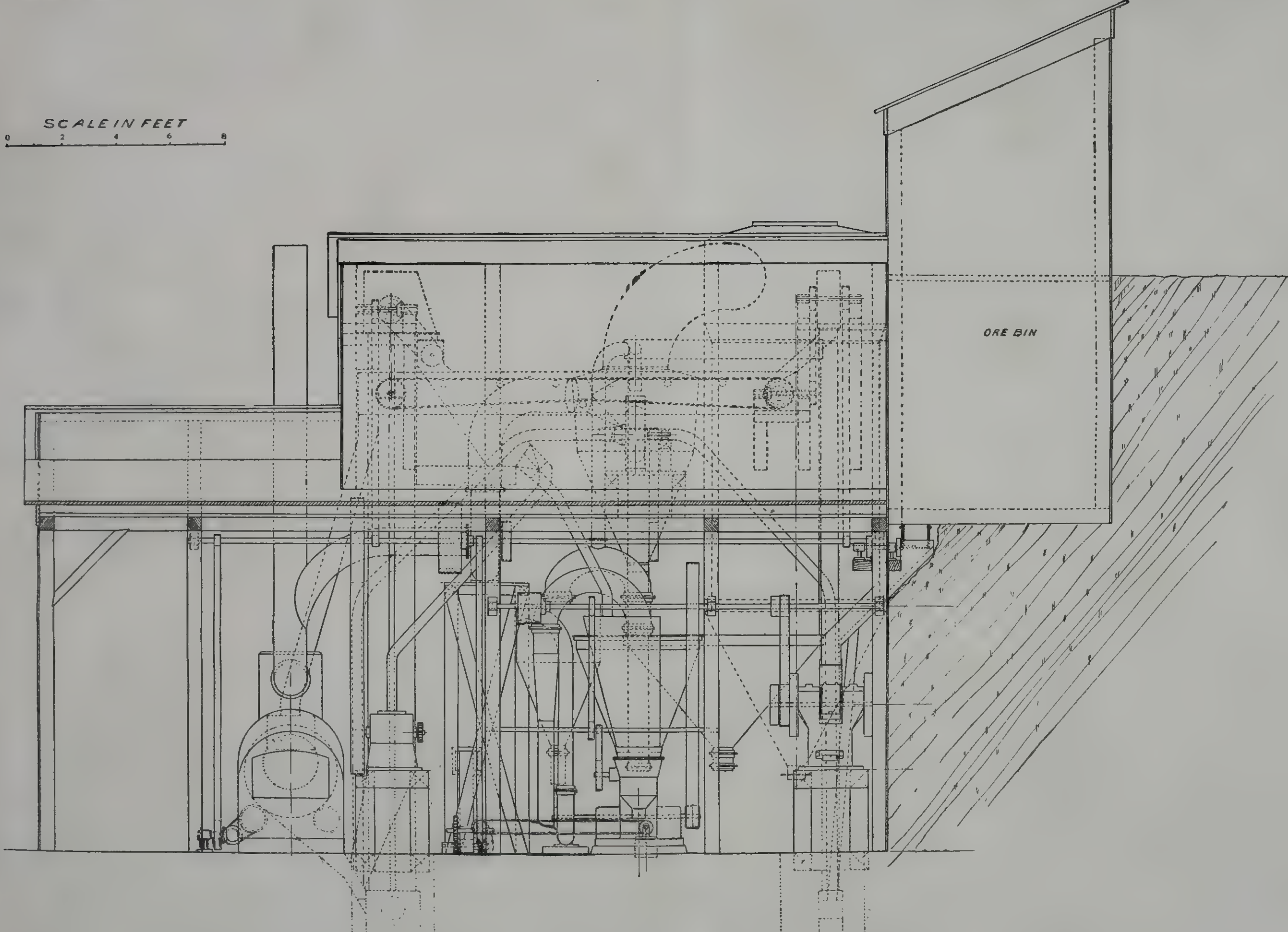
As already stated the concentrates were of four kinds, as follows: Concentrate No. 1, from the cyclone separator of the Raymond mill; concentrate No. 2, from the tubular dust collector; concentrate No. 3, from the cyclone separator for the mechanical drier and from the two dust traps connected with the auxiliary dust-collecting fan; and concentrate No. 4, from the dust collector or bag house receiving the gases, dust, and steam from the drier cyclone. The intake of the last was also connected through the blower fan with the crusher, elevator No. 1, the drier discharge spout, the rolls, and elevator No. 2, and all dust drawn off from them went into concentrate No. 4. The relative percentages of the four concentrates obtained in operating the mill were approximately as follows: No. 1 concentrate, 88 per cent; No. 2 concentrate, 2 per cent; No. 3 concentrate, 7 per cent; and No. 4 concentrate, 3 per cent.

In order to sample the feed and the tailings operation and estimate the approximate weight of ore fed or tailings discharged, small sampling devices were installed.

FEED SAMPLER.

The feed sampler was a chute or trough that passed periodically under the stream of ore from the automatic discharge hopper on the bottom of the ore bin, and thus removed a small sample.

This chute was made of No. 16 gage sheet iron and was 4 inches square and 3 feet long. It was pivoted at its lower end, the upper end being supported by a piece of strap iron, and was set at an angle of 40° with the horizontal. The movement of the sampler was pro-



SECTION *B-B* (PL. XII) OF CONCENTRATING MILL AT LONG PARK, COLO.

duced through a rod and lever actuated by a trip on a 3-inch belt. This belt was 17 feet 6 inches long and made one complete revolution every 50 seconds, pushing the chute under the ore stream once every revolution. A counterweight returned the chute to its original position. A sack at the lower end of the chute caught the portions of ore.

The sample obtained, which was something less than a hundredth part of the weight of the feed, was quartered by hand to approximately 25 pounds; then broken by hand to about $\frac{1}{4}$-inch mesh; and then reduced to 1 pound through a split sampler. The residue after being ground on a bucking board to pass a 40-mesh screen was reduced by a split sampler to approximately a quarter of a pound. This sample was tested with the electroscope.

TAILINGS SAMPLER.

For the tailings sampler more room was available, so that a sampler of somewhat different type was evolved. A sheet-iron tray 11 inches long, 1 inch deep, and $1\frac{5}{8}$ inches wide, with sides carefully filed to a knife edge, was suspended from $\frac{1}{4}$-inch rod hung between two parallel endless sprocket chains placed 14 inches apart. These chains were of No. 25 link belt and were $162\frac{1}{2}$ inches long, or exactly a hundred times the width of the tray. The sample represented just 1 per cent of the weight of the tailings.

The chains were driven by 3-inch sprockets. In passing the sprocket the tray turned completely over and its contents fell into a sack. The chain, guided by idler pulleys, carried the tray so that it passed through the stream of sand falling from the pulverizer discharge onto the conveyor and took one complete cut of this entire stream every 35 seconds. At the end of each day's run this sample was carefully weighed, and by multiplying this result by 100 the total weight of tailings produced was determined. The sample was usually fine enough to pass a 20-mesh screen and was reduced in a split sampler to the amount required for electroscopic tests.

SAMPLING OF CONCENTRATES.

All four products, concentrates Nos. 1, 2, 3, and 4, were sampled by means of a pipe sampler.

As carnotite concentrates are a very fine dust or powder which, being hygroscopic, quickly absorbs moisture from the air, they pack tightly, so that mechanical sampling is impracticable. It was found most suitable to sample the concentrates by means of a pipe or "cheese scoop" sampler, made of a piece of brass pipe about one-half inch in diameter and 30 inches long. About one-third of the pipe is removed to form a slot; that is, a strip lengthwise of the pipe is cut out, with the exception of about 4 inches on one end, to which a wooden handle is fastened. The lower end of the pipe is rounded

off and slightly sharpened. This sampler was pushed into each bag of concentrate in two different places. The pipe, filled with a representative cut of the concentrate, was then drawn from the bag and its contents were pushed out or the pipe was lightly tapped with a piece of wood. Two samples were taken from each bag. Each bag should be sampled in the same places in order to insure the sample being representative. The gross sample obtained was thoroughly mixed and coned, quartered, and finally split-sampled to the desired quantity.

ELECTROSCOPIC TESTS OF CONCENTRATES.

Field tests of concentrates in the electroscope are in general the same as for ore, as described under "Testing Ores." An important fact to be remembered is that the heat required to dry the ore for the Raymond mill drives off a certain amount of radium emanation from the ore, the amount varying with the degree and duration of heating. One-half of the emanation thus driven off will accumulate again in a period of 3.9 days, although approximately 30 days are required for the emanation to regain full strength. The amount of emanation driven off in heating the ore in the mill of the National Radium Institute during the winter months was approximately 5 per cent. Therefore, as this loss of emanation affected the apparent result in the electroscope, if the radioactive strength of the fresh concentrates showed a uranium oxide content of 3 per cent, it was safe to assume that they actually contained about $1.05 \times 3 = 3.15$ per cent. If, however, the test was not made until four days after milling, the error was only $2\frac{1}{2}$ per cent, which could be neglected because of its being less than the limit of accuracy with the electroscopic method. As proper mill control requires frequent tests soon after the concentrates are produced, a correction to be determined from time to time must be added to the result obtained by the electroscopic test.

TABULATED DATA ON OPERATION OF MILL.

The accompanying table gives complete data on the dry concentration of milling ore at Long Park, Colo. The results were obtained from operations on a commercial scale during the first months' run with the complete equipment and give an accurate idea of what can be expected from the dry process employed. The capacity of this mill was a little over 1 ton of milling ore an hour and the average output was 365 pounds of combined concentrates (Nos. 1, 2, 3, and 4) an hour.

The milling ore had an average content of 0.85 per cent U_3O_8; the average U_3O_8 content of the four kinds of concentrates was as follows: No. 1, 2.91 per cent; No. 2, 3.55 per cent; No. 3, 2.76 per cent; No. 4,

3.44 per cent; the total average of all four concentrates combined was 2.92 per cent U_3O_8.

Of the quantity of concentrates produced 87.77 per cent were collected as No. 1, 1.75 per cent as No. 2, 7.39 per cent as No. 3, and 3.09 per cent as No. 4. The tailings averaged 0.37 per cent U_3O_8.

The relatively high content of U_3O_8 in the tailings can not be conveniently recovered therefrom by only one mechanical operation, as microscopic examination shows that the carnotite left in the tailings is partly in pure hard particles about the size of the silica grains. Such particles could not be disintegrated without grinding up a large amount of the silica, which would go into the concentrates, reducing their uranium oxide content; also a small amount of carnotite is inclosed between the fractures of silica grains as fine as 150-mesh, and can not be liberated without grinding these grains to fine dust. However, the tailings are practically free from all adhering dust and carnotite.

The ratio of concentration was about 6:1, about 6 tons of milling ore yielding 1 ton of concentrates. Feeding richer ore, of course, lowers this ratio.

As much as 63.7 per cent of the carnotite contained in the milling ore was extracted and 60 per cent of all the carnotite in this ore was actually recovered in the concentrates, on the basis of the uranium content obtained by chemical analysis. In this statement "extraction" is considered as the difference in uranium oxide content of the feed and the tailings, whereas "recovery" is considered as the actual uranium content of the concentrate expressed as a percentage of the uranium content of the feed.

SUPPLIES USED.

In the operation of the mill, as shown by the table following, there were used 15.45 gallons of kerosene, 1.75 gallons of gasoline (to start engines), and about 283 pounds of coal per ton of concentrates produced; 2.7 gallons of kerosene and approximately 50 pounds of coal for each ton of ore milled were necessary to reduce the moisture in the ore to less than 1 per cent. The coal used was the best available cheaply in that section of the country; it has a heating value of about 10,000 British thermal units per pound.

During the period covered by the data presented the mill operated only one shift daily. Since then the mill has run with two shifts daily, but the figures obtained during this work were practically the same, with the exception of a slight saving on labor costs, as those given in the table following.

Results of first month's operations of complete concentration mill at Long Park, Colo.

Run No.	Time, hours.	Feed, dry weight (pounds).	U_3O_8 content of feed.		Dry weight of concentrates, pounds.					U_3O_8 content in concentrates.								
										Per cent.				Pounds.				
			Per cent.	Pounds.	No. 1.	No. 2.	No. 3.	No. 4.	Total.	No. 1.	No. 2.	No. 3.	No. 4.	No. 1.	No. 2.	No. 3.	No. 4.	Total.
1	53¼	111,100	0.8	888.8	16,680	300	1,630	382	18,992	2.9	3.5	2.7	3.21	483.7	10.5	44.1	12.3	550.6
2	61	123,000	.9	1,107.0	17,695	430	1,550	596	20,271	3.0	3.5	2.8	5.53	530.8	15.0	43.4	21.0	610.2
3	37	81,000	.8	648.0	11,700	160	1,360	453	13,673	2.9	3.9	2.85	3.49	339.3	6.3	38.7	15.8	400.1
4	48	98,500	.9	886.5	17,820	205	1,200	535	19,760	2.84	3.45	2.7	3.5	506.0	7.1	32.4	18.7	564.2
Total	199¼	413,600		3,530.3	63,895	1,095	5,740	1,966	72,696					1,859.8	38.9	158.6	67.8	2,125.1
Average			.85							2.91	3.55	2.76	3.44					

Run No.	Time, hours.	Feed, dry weight (pounds).	Tailings dry weight (pounds).	U_3O_8 in tailings.		Extraction, per cent.	Recovery, per cent.	Feed capacity, pounds.[a]	Amount of concentrates produced per hours' run, pounds.	Relative quantities of concentrates produced, per cent.				Ratio of concentration.
				Per cent.	Pounds.					No. 1.	No. 2.	No. 3.	No. 4.	
1	53¼	111,100	92,100	0.33	304.0	67.03	63.18	2,086	356	87.85	1.58	8.53	2.01	5.85 : 1
2	61	123,000	102,700	.40	410.0	62.96	55.12	2,016	332	87.30	2.12	7.64	2.94	6.06 : 1
3	37	81,000	67,300	.35	235.5	63.65	61.74	2,189	369	85.57	1.18	9.94	3.31	5.92 : 1
4	48	98,500	78,500	.42	329.7	63.93	63.64	2,052	411	90.19	1.03	6.07	2.71	4.98 : 1
Total	199¼	413,600	340,600		1,279.2									
Average				.375		63.7	60.2	2,086	365	87.77	1.75	7.39	3.09	5.69 : 1

SUPPLIES USED.

Run No.	Kerosene used.		Gasoline used, engines Nos. 1 and 2.	Coal used for drier.	Production of concentrates.	Kerosene used per ton of concentrate.	Gasoline used per ton of concentrate.	Coal used per ton of concentrate.	Quantity of milling ore treated.	Kerosene used per ton of milling ore.	Coal used per ton in drying of milling ore.
	Engine No. 1.	Engine No. 2.									
	Gal.	Gal.	Gal.	Lbs.	Lbs.	Gal.	Gal.	Lbs.	Lbs.	Gal.	Lbs.
1	72	92	14	2,650	18,992	17.27	1.49	279.00	111,100	2.95	47.70
2	86	91	16	3,350	20,271	17.46	1.57	330.52	123,000	2.87	54.47
3	43	53	11	2,060	13,673	14.04	2.34	301.32	81,000	2.37	50.86
4	56	73	16	2,200	19,760	13.05	1.61	222.66	98,500	2.61	44.67
Total	257	309	57	10,260	[b] 72,696	61.82	7.01	1,133.50	[c] 413,600	10.80	197.70
Average per ton of concentrates						15.45	1.75	283.38		2.70	49.42

[a] Dry weight, or 2,200 pounds wet weight.

[b] 36.35 tons.

[c] 206.8 tons.

PRODUCTION OF CONCENTRATES.

The following table shows the amount of concentrates produced at Long Park from the beginning of the experimental work to the closing of operations in August, 1916.

Production of concentrates to August, 1916.

[The net weights are for dry concentrates.]

Month.	No. 1 concentrate.		No. 2 concentrate.		No. 3 concentrate.		No. 4 concentrate.		Total.	
	Number of bags.	Net weight, pounds.	Number of bags.	Net weight, pounds.	Number of bags.	Net weight, pounds.	Number of bags.	Net weight, pounds.	Number of bags.	Net weight, pounds.
1915.										
(*a*)	2,119	103,620	86	1,660					2,205	105,280
November	283	25,496	46	3,663	53	4,744			382	33,903
December	155	13,950	39	3,510	37	3,330			231	20,790
1916.										
January	127	11,250	35	3,080	23	2,070			185	16,400
February	574	50,545	36	2,205	46	4,170	22	1,273	678	58,193
March	565	50,950	17	705	47	4,040	24	1,518	653	57,213
April	652	57,885	22	882	57	5,100	20	1,260	751	65,127
May	904	81,215	42	1,760	135	12,090	25	1,488	1,106	96,553
June	919	79,460	34	1,569	218	19,985	34	2,145	1,205	103,159
July, August	341	30,879	18	795	82	7,790	11	687	452	40,151
Total	6,639	505,250	375	19,829	698	63,319	136	8,371	7,848	596,769

a Produced during experimental tests.

RECOVERY OF CARNOTITE FROM LOW-GRADE ORES BY MECHANICAL CONCENTRATION.

Owing to the difficulty of separating the carnotite from the silica, extraction to be expected from mechanical concentration of low-grade ores is only relatively high. At least this is true of any of the methods that were fully tested. Therefore a recovery of 60 per cent of the carnotite in this low-grade ore, based on its known radium and uranium content, can be regarded as satisfactory with the equipment at hand.

Possibly with larger machines than those employed by the National Radium Institute a higher grade of concentrate can be obtained, as a large machine having a greater volume of air at lower velocity will separate much of the finely ground silica from the carnotite dust, but the concentrate would necessarily be considerably finer. Such machines, however, would be more costly, require more power, treat a larger tonnage—which is not always easily obtained from any one locality—and the extreme fineness of the concentrate would be probably a disadvantage in any acid leaching process for recovering radium.

POSSIBILITY OF RECOVERING CARNOTITE FROM MILL TAILINGS.

Tests were made to determine the possibility of a further recovery of carnotite from the mill tailings, which ordinarily contained about 40 per cent of the carnotite in the original feed. During one such test covering a day's run, in which about 5 tons of tailings were re-treated, a recovery of approximately 65 per cent was obtained, thus making the total recovery from the original mill feed approximately 85 per cent.

The National Radium Institute had only one Raymond machine in its mill, and, as operations had to be discontinued on account of the expiration of contracts, the tailings were left on the dump. Tests made during this work, however, show that in a new plant it may be advantageous to install a second Raymond mill to treat the tailings from the first. With one Raymond mill the material has to be rushed through in order to treat enough ore to make operation profitable. Under such conditions all of the carnotite can not be disintegrated, as the work of the beaters is largely to stir up the ground ore so the dust can be removed, but by running the dust-free tailings through a second Raymond machine the beaters can then act chiefly as grinders to liberate adhering carnotite and disintegrate grains that are not ground fine enough during the first operation. In re-treating tailings, the percentage of U_3O_8 in the concentrate can not be made as large as in the first operation, because silica is also necessarily ground up and is carried over into the concentrates, but a product averaging 1¾ per cent can be expected. However, running the additional machine adds comparatively little to the cost of operation and requires no additional labor, so that such re-treatment no doubt can be done at a profit.

Chapter IV. COSTS OF PRODUCTION.

The figures and costs given in the following pages include all expense for labor, supplies, repairs, insurance, general expense, and proportional amounts for amortization of equipment. The figures also include all costs of experimental work and equipment, as well as amounts credited to the Crucible Steel Co. for royalty on the ore mined from its claims, and the cost of cooperation of the Bureau of Mines. The cost of the shipping ore is given in a round sum, and represents an average of the costs over the entire period of mining by the National Radium Institute ended October 15, 1915.

The cost of concentrating the milling ore is also the average of the costs of concentrating during a period of several months.

SHIPPING ORE.

In calculating the cost of the shipping ore, containing about 2.6 per cent uranium oxide, or 52 pounds per ton of ore—three different figures are given in order to show the cost of the ore at the mine, at Placerville, Colo., and delivered at the sampling works of the National Radium Institute plant at Denver, Colo. These costs were as follows: Actual cost of mining this ore, which includes sorting but not sacking, approximately $36 per ton; cost of the ore at Placerville, approximately $61 per ton; and cost delivered at the Denver plant of the National Radium Institute, including all overhead charges and royalty, freight, and other expenses, $91.

These figures represent the average cost for approximately 960 tons of shipping-grade ore mined during about 15 months, and include 70 per cent amortization on mine equipment and buildings. Ordinarily this depreciation would be distributed over a longer period.

If cost figures for the various phases of the mining work, such as prospecting, sorting, and removing waste, are desired, the reader is referred to the chapter on mining, where various tables show the approximate percentage of time spent on each item; from these data and the values in the table following, it will be easy to compute such costs.

As regards mining cost of shipping and of milling ore, whenever milling ore was so associated with shipping ore that the milling ore had to be mined in order to get the shipping ore, the charge for mining the shipping ore included the cost of removing the milling

ore, but when the milling ore was mined by itself, the cost of mining it was separately entered and was not charged against the shipping ore.

Expenditures made by the mines department of the National Radium Institute during period of operation ended October 15, 1915.

Mine equipment and construction of mine warehouse	$980.49
Cost of automobile and live stock	655.00
Total cost of mining equipment	1,635.49
Cost of labor, net wages miners and foreman	20,550.00
Cost of commissary	11,481.75
Cost of mine supplies (including tools, steel, powder, fuse, caps, candles, water bags, blacksmith coal, etc.)	2,017.36
Cost of feed for live stock at mine	463.50
Total chargeable directly to mine operation	34,512.61
Cost of ore bags and twine	4,365.00
Cost of hauling ore to Placerville	19,913.63
Total cost for delivering ore at Placerville	24,278.63
Cost of loading ore into cars at Placerville and freight to Denver	8,245.00
General expenses at the mine (including office expenses, salary of office assistant at mine, telephone, telegrams, etc.)	1,516.98
Cost of maintenance of automobile	500.00
Cost of cooperation with the United States Bureau of Mines (including salary and travel expense of all members connected with the mining work).	6,906.90
Liability insurance, miner's compensation law	597.85
Total cost of general and overhead expenses	9,521.73
Cost of amortization on equipment (70 per cent of total cost, $1,635.49)	1,144.84
Cost of royalty to company owning claims	10,052.41
Total cost of royalty and amortization	11,197.25

SUMMARY.

		Total.	Per ton.[a]
Cost of mining ore	$34,512.61		
Cost of ore at the mine		$34,512.61	$35.96
Cost of delivering at Placerville	24,278.63		
Cost of ore at Placerville		58,791.24	61.24
Cost of loading and freight	8,245.00		
Cost of general and overhead expense	9,521.73		
Cost of royalty and amortization	11,197.25		
Total cost of ore delivered at Denver, including all charges		87,755.22	91.41

[a] Based upon production of 960 tons of shipping grade carnotite ore, net wet weight.

Commissary account.

Amount deducted for board from miners' wages	$11,075.95
Amount collected for board by petty cash account	244.08
	11,320.03
Commissary supplies on hand Oct. 31, 1915	500.00
	11,820.03
Amount paid for provisions and hauling to camp and cook's wages	11,481.75
Amount applied to amortization on camp equipment costing $876.90	338.28

As the National Radium Institute had contracted to do the assessment work on the 10 leased claims of the Crucible Steel Co. at Long Park, three years' assessment work, amounting to over $3,000, is included in the cost of mining the ore. Part of this, however, can be considered as actual cost of mining, as enough ore was obtained during assessment work to pay for such work. However, several claims were either nonproductive or produced so little that the assessment work, as far as the institute is concerned, must be considered a dead loss. The above calculation includes a charge of $10,052.51 for royalty, which of course would not have to be considered by a company working its own claim. However, such a company must charge off depreciation, and this charge should be considerably less than the royalty mentioned above. The actual cost of a pound of uranium oxide in the ore as mined by the National Radium Institute was $1.81 delivered at the Denver plant.

COST OF TRANSPORTATION OF ORE.

At first the National Radium Institute had its ore hauled to Placerville under contract at $20 per ton, all provisions and supplies, except machinery, being hauled to the mines free of charge. Later the contract was changed so that the rate was made $18 per ton and all haulage to the mines was paid for. As supplies were purchased at various points along the road, the prices for such back haul varied, as follows: From Placerville to the mines, $16 per ton; from Norwood, about 18 miles from Placerville, $11 per ton; from Redvale, $6.50 per ton; and from Naturita, the nearest town, $4 per ton. The mail and parcel post were carried free of charge.

As previously stated, most of the ore was loaded directly into the wagons, either at the claim or at the warehouse on the Maggie C claim. The ore from the outlying claims where the wagon could be driven up to the claim was loaded there. Some ore had to be packed a short distance to the road, as on the Great Western, Florence, and Bitter Creek claims.

For hauling the milling ore from outlying claims, and some of the milling ore mined underground on the Maggie C claim, to the ore bin of the mill a two-horse team, wagon, and driver were hired at $5 a

day. The teamsters staying over night at Long Park were boarded by the contractor, who had erected a small camp at a neighboring claim.

The freight rate on carnotite ore from Placerville to Denver was \$8 per ton, when a valuation of \$100 per ton was placed on the ore. A rate of \$6 per ton could have been obtained by reducing the estimated value of the ore to \$5 per ton, but the National Radium Institute found it of advantage to value the ore at \$100 per ton.

CRUSHING, GRINDING, AND SAMPLING OF THE SHIPPING ORE.

Before the National Radium Institute installed its own grinding and sampling plant at Denver, it had to pay \$4 to \$6 per ton for the crushing, grinding, and sampling of its ores. The cost of grinding and sampling in its plant averaged \$1.87 per ton of ore. This figure also includes 25 per cent amortization on the cost of building and equipping the plant.

Expenditures on grinding and sampling plant at Denver, Colo.

Equipment and construction		\$3,177.64
Cost of operation:		
Labor	\$726.30	
Supplies and repairs (including labor)	247.09	
Power	101.12	
	1,074.51	
25 per cent amortization on \$3,177.64	794.41	
Total cost for grinding and sampling 1,000 tons of ore		1,868.92

ROYALTY.

The royalty credited to the company owning the claims for all of the ore mined from the claims to October 15, 1915, on approximately 931 tons, net dry weight, of carnotite ore, amounted to \$10,052.41. The agreement was that the claims would be leased to the institute on a 15 per cent royalty basis, whereby 15 per cent of the ore mined from the claims was to be purchased by the institute at the price of \$2 per pound of uranium oxide content, f. o. b. Denver, Colo.

Royalties credited to company owning the claims for ore mined to October 31, 1915.

Car No.	Amount.	Car No.	Amount.	Car No.	Amount.
1	$268.37	10	$331.08	19	$494.25
2	435.30	11	386.82	20	416.60
3	425.68	12	421.11	21	438.77
4	460.64	13	495.12	22	387.96
5	381.21	14	333.57	23	374.53
6	321.38	15	540.68	24	461.40
7	335.68	16	505.99	25	219.15
8	389.69	17	407.19		
9	367.32	18	452.92	Total	10,052.41

Fifteen per cent of ore containing 48,344 pounds U_3O_8=7,251.6 pounds U_3O_8, at $2=$14,503.20.

Less expense of ore bags, freight, hauling, etc., $4,450.79.

Net royalty, $10,052.41.

COST OF CONCENTRATION OF MILLING ORE.

During the experimental stage of milling, the drying of the ore, the conveying of it from one apparatus to the other, and the removal of the tailings from the mill had to be done by hand labor. The cost per ton of concentrate during such work was therefore somewhat higher than with the completed mill. All of the ore used during the experimental work was taken from the most convenient places on the Maggie C claim.

The cost of concentration in the completed mill averaged $20.41 per ton, delivered at the mill warehouse. The concentrate averaged about 3 per cent U_3O_8 content. The cost given does not include the cost of mining, tramming, hauling, and sorting the milling ore, and of delivery into the mill ore bin after resorting, which averaged $7.14 per ton of concentrates. The cost of mining and concentrating the mill ore, including all mill supplies, labor, repairs, amortization on mill equipment and construction, was $27.55 per ton of concentrate, delivered at the mill at Long Park. To this has to be added $8.63 royalty; the cost of ore sacks, freight, and hauling, amounting to $33.10; and also amortization of equipment, taxes, accident liability insurance, and cost of cooperation with the Bureau of Mines. The cost of concentrates produced during the first month's run was therefore about as follows: $57.28 per ton delivered at mill warehouse; $75.28 per ton delivered at railroad station, Placerville, Colo.; $84.28 delivered at the Denver, Colo., plant; or, based on its U_3O_8 content, $1.44 per pound of U_3O_8 in the concentrate, f. o. b. Denver plant.

[Figures followed by an asterisk indicate items that, by the agreement between the National Radium Institute and the Crucible Steel Co., were included in the "cost of treatment" in figuring the royalty.]

Calculation of cost of concentration of carnotite milling ore.

[Runs 1, 2, 3, and 4. See p. 74 for details of operation.]

				Cost of concentrates per ton.
Labor			$468.58	$12.890*
566 gallons of kerosene, at 25 cents per gallon			141.50	3.892*
57½ gallons of gasoline, at 35 cents per gallon			18.98	.522*
5¼ tons of coal, at $8.50 per ton			43.52	1.197*
Oil, grease, water, etc			15.00	.412*
Repair parts and replacement of wearing parts on apparatus			54.53	1.500*
Chargeable directly to operation			742.11	20.413
Amortization on equipment and cost of cooperation			545.25	15.00
Accident liability insurance, and taxes			54.53	1.50*
			1,341.89	36.913
Cost of mining, sorting, picking, and hauling of milling ore to mill ore bin			259.38	7.135*
837 ore bags and twine, at 20 cents each			167.40	4.605
Cost f. o. b. mill, Long Park, Colo			1,768.67	48.653
Hauling to Placerville, Colo			654.30	18.00
Cost f. o. b. Placerville, Colo			2,422.97	66.653
Receiving and loading on cars at Placerville			18.18	.50
Freight to Denver, Colo			290.80	8.00
Unloading and sampling			18.18	.50
Royalty, 15 per cent on 2,125.1 pounds U_3O_8, at $2 per pound f. o. b. Denver		$637.53	2,750.13	75.653
Less 15 per cent of the following charges:				
Cost of treatment, at $29.05 per ton	$154.16			
Ore bags and twine	25.11			
Hauling to Placerville	98.14			
Receiving and loading at Placerville	2.73			
Freight	43.62			
		323.76		
Net royalty			313.77	8.631
Total cost of concentrate f. o. b. Denver plant			3,063.90	84.284

Cost per pound of U_3O_8 in concentrates $1.44 f. o. b. Denver plant, or $84.29 per ton of concentrates.

COST OF CONCENTRATION MILL.

The cost of the complete mill as built and operated by the National Radium Institute was $10,000, which covers the cost of all material and equipment, including freight charges and haulage, and the construction work. The figure given includes a small sum for additional expenditures made for experimental work and for apparatus which was discarded, as well as the expense incurred in reconstruction when the change to the completed mill was made.

PUBLICATIONS ON MINERAL TECHNOLOGY.

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TECHNICAL PAPER 143. Ores of copper lead, gold, and silver, by C. H. Fulton. 1916. 41 pp.

PUBLICATIONS THAT MAY BE OBTAINED ONLY THROUGH THE SUPERINTENDENT OF DOCUMENTS.

BULLETIN 11. The purchase of coal by the Government under specifications, with analyses of coal delivered for the fiscal year 1908–9, by G. S. Pope. 80 pp. 10 cents.

BULLETIN 12. Apparatus and methods for the sampling and analysis of furnace gases, by J. C. W. Frazer and E. J. Hoffman. 1911. 22 pp., 6 figs. 5 cents.

BULLETIN 22. Analyses of coals in the United States, with descriptions of mine and field samples collected between July 1, 1904, and June 30, 1910, by N. W. Lord, with chapters by J. A. Holmes, F. M. Stanton, A. C. Fieldner, and Samuel Sanford. 1912. Part I, Analyses, pp. 1–321; Part II, Descriptions of samples, pp. 321–1129. 85 cents.

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Technical Paper 60. The approximate melting points of some commercial copper alloys, by H. W. Gillett and A. B. Norton. 1913. 10 pp., 1 fig. 5 cents.

Technical Paper 90. Metallurgical treatment of the low-grade and complex ores of Utah, a preliminary report, by D. A. Lyon, R. H. Bradford, S. S. Arentz, O. C. Ralston, and C. L. Larson. 1915. 40 pp. 5 cents.

Technical Paper 93. Graphic studies of ultimate analyses of coals, by O. C. Ralston, with a preface by H. C. Porter. 1915. 41 pp., 3 pls., 6 figs. 10 cents.

Technical Paper 109. Composition of the natural gas used in 25 cities, with a discussion of the properties of natural gas, by G. A. Burrell and G. G. Oberfell. 1915. 22 pp. 5 cents.

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